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AERONAUTICAL MOTOR

INSTRUCTION PAPER

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AERONAUTICAL MOTOR

Early Types. In the general acclaim that has greeted man's final conquest of the air, the chief contributing factor that has made it possible has to a great extent been overlooked. Power in sufficiently concentrated form appears to have been the only thing lacking for at least half a century past to have made possible for two or three generations what has been the reality of less than a decade. Not that a perfected light-weight power unit was sufficient in itself, as there are numerous principles governing flight that have been discovered only in recent years, but it was the one thing needed to lift a heavier-than-air machine from the ground and to keep it in the air. With its aid, it appears to be more than probable that the problem of the sustaining plane and the difficulties of equilibrium would have found a solution at a much earlier date. That at least one far-sighted investigator had realized the possibilities of the monoplane is shown by Henson's machine of 1843. Henson's steam engine was justly considered a marvel for its anticipated numerous features that are generally considered as the development of but very recent years in this form of prime mover.

But despite the great improvements it embodied and the fact that it could be operated continuously on but 20 gallons of water, its output was but 20 horse-power for a total weight of 600 pounds. Compare this low limit of 30 pounds per horse-power, of sixty years ago, with the 1.75 pounds per horse-power of the 140-horse-power Gnome motor and the advance that has been achieved will be appreciated. "Continuously" in this connection meant just what it does today—as long as the fuel holds out—and as coal is not only excessively heavy but likewise very inefficient for its weight when burned under a boiler, as compared with gasoline used directly in an internal combustion motor, it is evident that even with the great supporting power afforded by the 4,500 square feet of surface of the main planes, Henson's craft could not have carried sufficient coal to permit of much of a flight.

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That extremely light weight was not the only desideratum is shown by Maxim's engine of 1892, which totaled only 600 pounds for an output of more than 360 horse-power, or actually less than 2 pounds per horse-power by an ample margin. The boiler weighed in the neighborhood of 1,800 pounds. The engines were compound and by an ingenious regulating device the high-pressure steam passed direct to the low-pressure cylinders when the boiler pressure exceeded 300 pounds per square inch, for which it was designed. This increased the output to 400 horse-power, the piston speed being 750 feet per minute, or more than a third less than what is now common practice with the internal combustion motor. While Maxim's engine, boiler plant, and equipment were extremely light for the power output, they had to work under the great disadvantage inseparable from the use of steam—that is, the low thermal efficiency of burning fuel under a boiler and the consequently increased amount that has to be carried. While ample sustaining area had been provided for this and similar purposes (4,500 square feet) the weight of the fuel necessary for a comparatively short flight would easily have exceeded that of the entire power plant. Apart from this the space *required* for the machinery was out of all proportion to the total space *available*, particularly as it would have been more or less essential to be able to get at the various parts of the plant during a flight.

In this case, the saving in weight was accomplished only at the expense of other disadvantages that would have rendered the final result immature had the machine been developed to a point where it could be actually employed in flight. But in looking back over the history of attempts at power-driven airships, it will be apparent that weight has been by far the greatest deterrent to success. For instance, Giffard's steam engine and boiler employed for driving a dirigible, in 1852, weighed 350 pounds, including coal and water, for an output of 3 horse-power. Dupuy De Lôme's dirigible of about twenty years later was a step backward in this respect, in that human power was employed. This meant a weight of close to 2,000 pounds per horse-power, while the maximum power would naturally be available only for short periods. The Tissandier electric power plant of 1882 had inherent limitations of so serious a nature where weight and restricted traveling radius were concerned that it can scarcely be considered as more than a freak. No one

conversant with the drawbacks inseparable from electric power for this purpose would have made the attempt. The 1½-horse-power motor and its battery of primary cells weighed 500 pounds and the type employed (bichromate cells) was such that the power was available only for a very limited period. Despite these disadvantages the first dirigible to attain any measure of success was driven by electricity. This was the La France of 1884, equipped with an 8-horse-power motor, which has been referred to already in the earlier part of the work.

To Santos-Dumont doubtless belongs the credit of being the first to realize the great possibilities of the gasoline motor for aerial navigation. How he derived his inspiration from the motorcycle engine and the numerous attempts he made with dirigibles have already been dwelt upon. His first motor weighed between 15 and 20 pounds to the horse-power and, like everything he has been responsible for in connection with aeronautics, was designed on a very small scale, its total output not exceeding 4 horse-power. Although a pioneer in the field, Santos-Dumont has not been responsible for the subsequent development of the gasoline motor. At the time he took it up, the first stages of its evolution for automobile propulsion were being passed through and the difficulties encountered were so numerous and, in many instances, of such a puzzling nature, that it is easy to realize why attention was concentrated on perfecting it for a purpose that did not involve the further problems of successful flight. The history of the past twenty years shows that the development of the automobile motor was no small task in itself. With this fairly accomplished, the next step was principally one of refinement and adaptation.

GENERAL MOTOR REQUIREMENTS

To bring about its required refinement and adaptation in the aeronautic motor seems a comparatively simple matter, but that it has not proven so in fact will be realized upon reviewing the innumerable expedients that have been adopted by different builders to meet the conditions, and the many departures that these have involved from what may be termed automobile practice. In fact, in the few years devoted to its design, practically a new type of motor has been evolved. In order to obtain a clear understanding

of how this has been brought about, it is first necessary to realize how exacting the requirements are and of just what they consist. Following this with a study of some of the more representative types that are now built for aeronautical use will reveal how the various principles laid down have been applied in each case. Before taking this up in detail, it may make matters a little clearer to briefly compare the automobile and the aeronautic motor.

Automobile vs. Aeronautical Motor. Generally speaking, the trend of the past few years, where the automobile motor is concerned, has been to develop a power unit of more uniform torque and of increased efficiency. The more general adoption of the six-cylinder motor and the increase in the length of the stroke, as compared with the bore, afford evidence of this. Little or no attention is now given to the question of weight saving, apart from any reduction that the use of integrally cast inlet manifolds, more direct water circulation, and similar efforts at cutting down the length of piping, may have been responsible for. Weights have reached a point where any substantial reduction could be brought about only by a more or less radical change in methods of construction, as well as the use of much more expensive materials. There would be little to warrant the increased cost of a much lighter motor, besides which it would involve the use of a higher speed to develop the same power with less weight. More important than any of these considerations is the fact that reliability suffers as the weight decreases.

Consequently, the tendency in the development of the automobile motor during the past few years has been mainly along the line of increased efficiency with practically no regard for the matter of weight, while the chief aim of the builder of aeronautical motors has been to get the latter down to the minimum. But that weight saving is not the sole governing factor in the design of a successful motor for flying is amply evidenced by the fact that the first aeroplane ever to make a flight—that of the Wright Brothers—was equipped with a comparatively heavy motor. Nor has this motor undergone any radical changes since it was first adopted several years ago. Like the Wright biplane of standard type, it is not only heavier but develops less power than many other experimenters have thought necessary for the purpose. But in it efficiency and reliability have been developed to a high degree and these vastly

important qualities are very largely responsible for the numerous successful flights and for the high standing which the Wright machines enjoy in the field of aviation.

It did not take long, however, to reach a point in the development of the aeroplane where the speed of 40 miles an hour of which the Wright biplane was capable, was considered slow. The demand was accordingly for more and more power—the greater the driving force available, the smaller the sustaining surface needed, with a consequent reduction in the wind resistance. To meet this demand and still keep the weight down, every imaginable expedient has been resorted to by designers.

It has been said that the most important problem in the design of a light motor is the correct choice of type, but when what has already been accomplished in this field is passed in review, it will be found that there are aeronautical motors of every type ever tried on the automobile and many for which the latter was not responsible. Not all of them are successful, of course, but many of such widely differing types have attained such a measure of success that there is no telling what the advances of the next five years may be.

Fundamental Features of Design. *Short Stroke.* As an aeronautical motor of small bore and long stroke is much heavier in comparison to its power output than one in which these two dimensions are more nearly the same, design in this field has naturally gone back to automobile standards of several years ago when it was customary to build what are known as *square* motors, *i. e.*, those in which the bore and stroke are the same. In fact, it was nothing unusual for the bore to exceed the stroke. The advantages of a long stroke are increased efficiency and somewhat smoother running, the greater fuel economy and reduced vibration compensating for its inferior weight efficiency on the automobile. The majority of aeronautical motors are accordingly of the short stroke type, as the weight decreases very rapidly with a reduction in the length of the stroke. This was strikingly illustrated in the case of a large motor built for the Vanderbilt Cup race a few years ago. Its original dimensions were 7-inch bore by 7-inch stroke. In re-designing this motor, it was made 7 by 6 inches, the 1-inch reduction in the stroke being responsible for a saving of almost 200 pounds. The short-stroke motor has the further advantage of a low center of gravity.

Cost No Object. While compelled to reconcile numerous conflicting requirements, such as that of maximum reliability with the minimum weight, the designer of the aeronautical motor is not hampered so much by questions of cost. Consequently, many refinements of construction are available that could not be indulged in on the automobile motor. For instance, pistons are finished all over, inside and outside, and in some cases, the cylinders themselves are machined direct from a bar of solid steel at a cost many times greater than that of casting them of iron. Pistons in some cases are made of steel in order to attain the minimum thickness of wall, and every possible opportunity is taken advantage of to reduce weight, such as making the piston extremely short—even shorter than the stroke in some instances. Pressed steel is resorted to in the making of the connecting rods, or, where forgings are employed, they are simply riddled with holes to get rid of every ounce of metal.

Low Weight per Horse-Power. It must be borne in mind that, even at this early day, there are radically different standards among builders of aeroplanes. Some are constructed for purely sporting purposes. There are racing machines and touring machines, if the latter appellation be permissible. In the case of the former, the motor must develop a great amount of power for a comparatively short period. The fact that its construction is not particularly durable makes it possible to practically eliminate the question of any factor of safety in its parts. The latter are shaved down to the last fraction of an ounce and reliability is sacrificed in consequence, but before going into action the motor will be tuned up to its highest pitch, and if it will run long enough to cover a certain distance, that is all that is necessary.

Even aluminum has been employed for cylinders in rare instances, the bearing surface for the piston consisting of a thin cast-iron bushing forced into the aluminum casting. This has the great disadvantage of providing an aluminum explosion chamber and this metal loses its strength very rapidly as the temperature increases above a certain degree. It likewise involves the most expensive form of construction in that harder seats must also be employed for the valves, aluminum being entirely too soft for this purpose. Aluminum cylinder heads have also been employed with cast-iron or steel cylinders, but considerable trouble has been experienced with them

owing to the great difference in the ratio of heat expansion between aluminum and cast iron or steel. Consequently, aluminum is no longer employed for such important parts.*

In addition to drilling the connecting rods, they are usually made very much shorter than in automobile practice, this being as low as 1.5 to 1.75 times the length of the stroke in motors of a type which are inherently well balanced by reason of their design, such as the six-cylinder vertical or the three-cylinder radial. It will seldom be found to exceed 2 to 2.25 times the stroke, the evil of increased friction of the piston against the cylinder walls due to the greater angularity of the short connecting rod being partly compensated for by offsetting the crank shaft with respect to the cylinder center. By this means, the pressure between the piston and cylinder wall are practically equalized on the compression and power strokes. The crank shaft, cam shaft, and even the valve lifters are drilled to reduce weight, the passages thus made eliminating every bit of unnecessary material, and affording convenient means of lubrication.

Automatically-Operated Inlet Valves. In this connection, a further reversion to what is now obsolete in the automobile motor is to be considered. This is the employment of automatically-operated inlet valves. In view of the fact that the aeronautical motor is seldom called upon in service, to vary its speed much, the high degree of flexibility to which the automobile motor has been developed is of no particular advantage and the shortcomings of the automatic type of valve are not a serious drawback. Probably no better instance of the employment of the automatic valve could be mentioned than the Gnome revolving-cylinder motors.

As is the case with most other important parts of the aeronautic motor, experience with the automobile has been drawn upon

*In general, however, aluminum or aluminum alloys have been used wherever it is possible to substitute these alloys for the heavier metals, such as iron or steel. The attempt to use them for casting the cylinders is not new, but aluminum itself is not suitable and difficulty has been found in making a proper alloy. But within the past year (1911) magnalium has been successfully employed for this purpose. This consists of pure aluminum with a slight percentage of the metal magnesium and the resulting alloy is not only denser but is about 12½ per cent lighter than No. 12 aluminum, which consists of 93 per cent aluminum and 7 per cent copper, and has a specific gravity of 2.82. Magnalium accordingly weighs about one third as much as cast iron, while its thermal conductivity is seven to eight times greater, which greatly facilitates the cooling, especially of air-cooled engines. Unlike other aluminum alloys that have been employed for cylinders, tests have demonstrated that it gives better service than iron under the same conditions, as the bore of a magnalium cylinder takes on a mirror polish after only a few hours running, while the surface becomes very hard, as has been shown by the piston and rings of a poorly-bored cylinder becoming scored instead of the cylinder walls, as would usually be the case. Owing to its greater strength as well as reduced weight, it is also being employed for crank cases and other motor parts. The expense, however, would be prohibitive for anything but an aeronautical motor.

in the placing of the valves. The high-speed automobile motor has shown that the most advantageous valve arrangements are those in which the valves are in the head, and the so-called De Dion arrangement in which the valves are in line with each other. The reasons for this will be obvious when it is borne in mind that power is obtainable only with high speed where the valves are very liberally proportioned with regard to the cylinder bore. The combined inlet and exhaust valve, as developed on the Franklin air-cooled motor, has also been successfully applied to the aeronautic motor. Placing the valves in the head makes possible a very simple form of explosion chamber with a minimum of wall surface, with consequently increased thermal efficiency as compared with a form of cylinder head involving the use of valve pockets. The absence of the latter prevents the retention of spent gases, which gives increased power and fuel efficiency by reducing the tendency to premature ignition and by the use of higher compression pressures, which mean higher temperatures. The importance of this is obvious in view of the close weight limitations, and it is accordingly customary to employ higher compression pressures and speeds than in the automobile motor. Considerable interest at present attaches to the development of motors with rotary valves, or sliding sleeves and ports instead of valves, as in the Silent-Knight motor. So far little definite progress appears to have been made with the adaptation of this type of motor to the aeroplane, but numerous attempts are being made to evolve a practical form of rotary valve. The Knight motor itself does not offer any advantages of either simplicity or reduced weight so that the solution does not lie in that direction. An interesting development where the valves are concerned is found in the Adams-Farwell rotary motor in which the fuel is injected directly into the cylinder so that only one valve is necessary for each cylinder, and this can accordingly be made of very liberal diameter.

Standard Forms. The foregoing will suffice to give some idea of the difference in design and requirements between the aeronautic and the automobile motor, as well as those features of the latter which have been found advantageous in the new field. But so far, merely the parts themselves have been touched upon. It is in their assembly that the greatest divergence between the two standards is found. A glance over the numerous types that are

sufficiently successful to remove them from the class of freaks, or mere proposed forms of construction that have not yet got beyond the paper stage, reveals the fact that every form of automobile motor that has ever been devised, has its counterpart among the newcomers, besides many which were never thought of in that connection. At one end of the list, there is the single-cylinder, air-cooled, motorcycle engine with which Santos-Dumont made his first attempts at dirigible propulsion, and at the other the highly refined and extremely ingenious fourteen-cylinder revolving Gnome motor, and the sixteen-cylinder **V**-shaped Antoinette. Between these two there is every form imaginable, even the two-cylinder horizontal opposed—that hybrid type of purely American origin and development, which foreign designers have always affected to despise, now being built by some French makers.

V-Form. The **V**-form, or 90-degree arrangement in which each pair of cylinders acts upon the same crank pin is very largely employed, both the Wright Brothers and Curtiss using this type in their more powerful machines. This arrangement permits of using a crank shaft of practically the same dimensions as a four-cylinder motor of the same size and is accordingly a great saving of weight. It also makes it possible to actuate all the valves from a single cam shaft, placed in the point of the **V**. From this arrangement, developments have led to the placing of three cylinders round a common crank case in the same vertical plane, also seven cylinders, three in one plane and four in another, as in the Esnault-Pelterie motor. Motors of this and similar arrangement are popularly referred to as "fan" and "star" types, and as all the cylinders act on the same crank pin, and the valve gear is reduced to its very simplest form, the saving in the weight of the crank shaft and crank case thus effected may readily be appreciated. When first attempted such motors did not give much promise of being practical, but as they have proved such a success in actual use, they are now one of the most popular forms of light-weight motors. Their chief disadvantage lies in the amount of space occupied in the direction across the cylinders, making them awkward for use in a dirigible for which a specially designed basket or car of greater weight is necessary.

Revolving Cylinder. Of even less promise at the outset was the revolving-cylinder motor, in spite of the fact that this type had been

developed to a high degree of reliability and efficiency in the Adams-Farwell car. In addition to the other difficulties of design, the gyroscopic effect of the revolving mass had to be taken into consideration. It is well known that a large flywheel, revolving rapidly, forcibly resists any attempt to change its plane of rotation, advantage having been taken of this principle to balance a mono-rail car on its single support, and to keep torpedo boats steady in a seaway. While the revolving-cylinder motor dispenses with a flywheel, its revolving mass acts in the same rôle and plays the part of a gyroscope. Placing the latter horizontally would tend to increase the stability of an aeroplane without appreciably affecting its steering, but it was thought that where run in a vertical plane, as is necessary in order to obtain direct driving of the propeller, it would interfere with rounding curves of short radius. In the case of the Bleriot monoplanes with a revolving-cylinder Gnome motor right up forward, this does not appear to have been the case.

The chief advantage of this form of motor is its ability to dispense with a flywheel of any kind and its highly efficient air cooling. The latter has proved effective even with motors of comparatively large size, using an initial compression as high as 75 pounds to the square inch. One thing that the aeronautic engine designer does not have to contend with is dust and grit, so that in some instances all provisions for excluding it have been omitted.

Correspondingly greater difficulties are found, however, in the very important essential of lubrication and in the disposition of the piping. Special means have to be resorted to in order to insure the oiling of every moving part, particularly where centrifugal force enters to complicate the problem, as in the revolving cylinder motor. The lubricating system employed on the most representative type of the latter—the Gnome—is very effective but likewise very wasteful, as the oil is merely pumped through the motor and out into the air. But even in the V- and fan-shaped motors, where the cylinders stand directly over a crank case, as on an automobile motor, splash lubrication can not be employed. The last cylinders in the direction of the motor's rotation would receive very little oil. Fewer difficulties are encountered with the lubrication of motors having their cylinders placed horizontally and provided with a vertical crank shaft, as in the case of the Farcot and Clement engines.

The problem of properly arranging the piping is one that has led to numerous ingenious expedients, such as the employment of independent feed pumps for each cylinder on the eight- and sixteen-cylinder Antoinette, instead of a carbureter and the usual complicated inlet manifold. The latter is even more cleverly dispensed with in the case of the Gnome revolving motor, in which the mixture of air and gas is led through the hollow stationary crank shaft, the different cylinders receiving their supply through automatic inlet valves placed in the heads of the pistons. Where the flying machine is concerned the question of piping has one redeeming feature in that it is permissible to exhaust directly into the air. No one but the pilot of the aeroplane is inconvenienced by this, but the roar is such that it is quite likely a muffler will be a feature of the aeroplane motor before very long. On the dirigible, it would naturally be very dangerous to permit the escape of the exhaust anywhere near the gas bag, and accordingly a muffler is not only employed, but in some cases both the exhaust and the muffler are water cooled to make certain of reducing the temperature of the exhaust to a safe limit.

Flywheel. One other advantage enjoyed by the aeronautic motor is the fact that it is possible in most instances either to dispense with the use of a flywheel altogether, or reduce its weight to an almost negligible factor. But just as early investigators in the automobile field did not appreciate the full value of a heavy flywheel, so some designers of aeronautic motors do not consider it as important as it really is, in view of the particular types of motors they employ. Naturally, the conditions are quite different, as the propeller, though very light, is of large diameter and where directly attached to the crank shaft, does away with the necessity for a flywheel. In reviewing the large number of aeronautic motors now on the market, which is done more in detail a little further along, all shades of opinion will be found represented where this ordinarily important essential is concerned. They range from the conventional cast-iron flywheel of automobile type found on the Wright motor to a perforated-steel stamping, as in the Vivinus, or none at all, this being the case even on two-cylinder, horizontal-opposed motors in which the impulses are very intermittent. Examples of this are found in the Darracq and the Deuthil-Chalmers, both of French make.

Number of Cylinders and Weight Saving. Mention has already been made of the fact that there is a great diversity of opinion among aeroplane motor designers regarding the number of cylinders. As the weight of an engine may be roughly divided into cylinders and pistons on one hand, and the crank case and crank shaft on the other, assuming the conventional type it will be evident that the number of cylinders has a direct bearing on a most important factor—that of weight. In the numerous "spider" types of motors—if they may be so called—those in which the cylinders radiate from a very much abbreviated crank case with a correspondingly reduced crank shaft, this proportion naturally does not hold good. There are, of course, many other factors to be considered in the selection of the proper number of cylinders and it will be apparent from a study of the examples illustrated and described that designers have become very largely divided into three general classes: Those favoring what may be termed the conventional type, through its familiarity on the automobile—that is, the vertical or V-arrangement of cylinders; those who favor variations of the radial arrangement; and those who pin their faith to the revolving motor, this really being a subdivision of the second class.

Assuming a constant r. p. m. rate, both the power output and the weight of a cylinder increase as the product of D^2L, D denoting the diameter of cylinder, L the length of stroke; but if a constant piston speed be assumed, such as the standard of 1,000 feet per minute adopted by the Association of Licensed Automobile Manufacturers, on which to base motor ratings, the power, only, increases as the square, while the weight still increases as the product of D^2L. For moderate powers, the actual weight of the cylinders themselves appears to be but little influenced by their number, but it will be obvious that with any substantial increase in power, the weight of a smaller number of comparatively large cylinders should be less owing to the difficulty of reducing the thickness of the cylinders in proportion to their reduced dimensions. Experience has also shown that an engine with a few large cylinders has a very much higher factor of reliability and is easier to maintain, than one with a large number of small cylinders. While exceedingly fast time has been made over short stretches by an eight-cylinder V-type automobile motor—the 200-horse-power Benz—the fastest time in

road races over long distances has thus far always been to the credit of the four- or six-cylinder motor of conventional design.

In addition to almost eliminating the crank case, the small multi-cylinder radial type also dispenses with the flywheel. This last, of course, is equally true of any motor employing six or more cylinders, as the multi-cylinder motor has the great advantage of producing a much more even turning moment. The drive is not continuous in a four-cylinder motor and, theoretically, it will not run at all without a flywheel. However, as the motor is directly connected to the propeller in the majority of instances, the latter is frequently found an efficient substitute. The more uniform torque of the motor with the greater number of cylinders is an added advantage in not imposing such severe stresses on connections as is the case where a smaller number of power units is employed. But the question of reliability enters here again, and as there is always the possibility of one or more cylinders of the multi-cylinder motor ceasing to fire, the reversal of stresses is then quite as great as with fewer cylinders.

Coming back to the question of weight saving—and at the present time it is evident that this is the chief controlling factor—let us see what are the steps leading up to the extremely light-weight modern motor. With the conventional arrangement, *i. e.*, cylinders vertically in a row, the weight of the crank case and crank shaft naturally increase in proportion to the cylinder capacity. By placing two rows of cylinders on the same crank case, as in the usual V-arrangement, the size of the crank case and crank shaft are but slightly larger than for the single row and the weight is cut almost in half. With eight cylinders at 90 degrees, the impulses are evenly spaced throughout the revolution, each pair of opposite cylinders being connected to one crank. But both impulse and mechanical balance are obtainable with as small a number as two cylinders, where the latter are arranged in what is known as the horizontal-opposed motor. The cylinders are slightly offset on opposite sides of a very short crank case and they act upon oppositely-disposed cranks—in other words, a two-throw crank shaft with the pins placed 180 degrees apart. This gives a very smooth running motor where two or any multiple of two cylinders are employed.

The advantages of this type are mentioned at greater length

here as they have only recently received that measure of appreciation which they deserve, as will be noted later in the successful motors of this type that are now in use. While the crank case and crank shaft of the horizontal-opposed motor increase in proportion to the increase in cylinder capacity, as compared with the diagonal or "spider" motor, the impulses are more even and the balance better than in the latter when using less than four cylinders.

In order to give the student a clearer idea of the manner in which the crank case and crank shaft are affected by the arrangement of the cylinders, with a corresponding reduction in the weight, the accompanying illustrations may be referred to. In these sketches the details have been intentionally omitted to

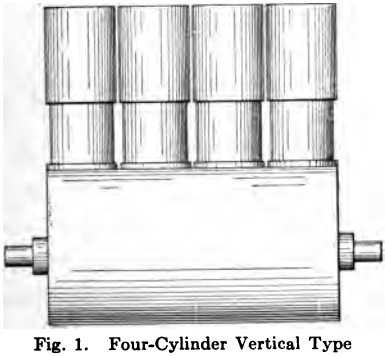

Fig. 1. Four-Cylinder Vertical Type

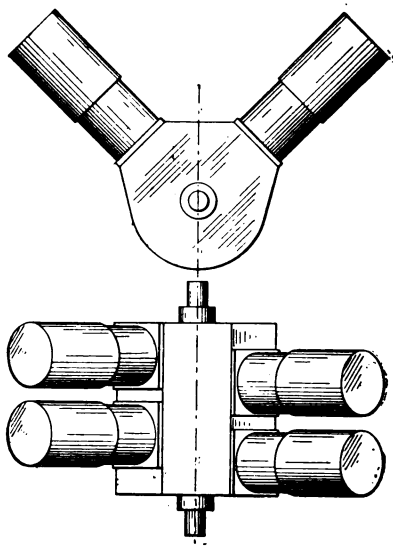

Fig. 2. V-Type of 2 to 16 Cylinders

prevent confusion; in actual practice, the space between the open ends of the cylinders on the crank case would be very much less than is here indicated. Fig. 1 is the conventional four-cylinder vertical motor as employed on the automobile. In this case the crank case must necessarily be slightly longer than that of the combined length of all the cylinders. The first step away from this is the V or 90-degree arrangement, as shown by Fig. 2, which illustrates the elevation and the plan. A similarly great reduction in the size of the crank case is effected by the horizontal-opposed arrangement, Fig. 3. Either the diagonal or opposed arrangement lends itself readily to two, four, six, eight, ten, or more cylinders, motors of

the diagonal type being built with as many as sixteen cylinders. The first step away from this type is what has previously been referred to as the fan or radial arrangement as shown by Fig. 4, also as carried further by the addition of an extra pair of cylinders, as in Fig. 5.

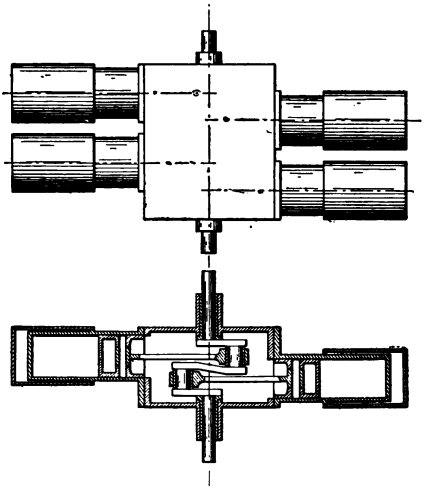

Fig. 3. Horizontal-Opposed Type

This type naturally does not lend itself as well to water cooling as the first, second, and third arrangements illustrated, owing to the necessity of providing an independent jacket for every cylinder with the attendant complication in the piping. But for air cooling this type is ideal, as the cylinders are so spaced that each one receives an equal amount of air and none can radiate its heat directly to any of the others. The question of water versus air cooling is naturally again to the fore in this field, but under very different conditions for the latter than where the automobile is concerned. Whether directly

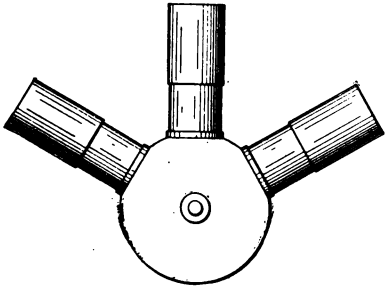

Fig. 4. Three-Cylinder Fan Type

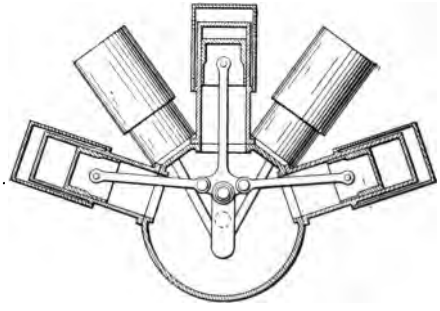

Fig. 5. Five-Cylinder Fan Type

connected to the propeller or used to drive the latter through a transmission system, the motor itself is always completely exposed to the air and is cooled by a current averaging 40 to 60 miles an hour, or even greater. There would appear to be no possibility of ever working an air-cooled motor so hard, even on a warm summer day,

as to cause it to be any less reliable on the score of danger of overheating, where the conditions are so favorable. On the other hand, with a multi-cylinder motor of the radial type, the complications of the piping system and connections would be a source of danger in themselves. For numerous reasons, none of which appears to have the slightest bearing on its efficiency or reliability as judged from a purely engineering viewpoint, the air-cooled motor has a rather limited use in the automobile field.

Where the aeroplane is concerned, however, weight saving is of vital importance and space is also a factor which must be closely considered. The designer of aeroplane motors is neither hampered by restriction of style nor by a commercial demand. He does not have to cater to a buying public that has to a great extent conventionalized automobile design, by refusing to aid the manufacturer whose designs in any way departed from the conventional. It accordingly seems quite probable that the question of air cooling will be worked out on the aeroplane motor from a purely engineering viewpoint. Even where the cylinders of a radial type of motor, such as that shown by Fig. 5, are placed so close together there should be no difficulty in properly cooling them.

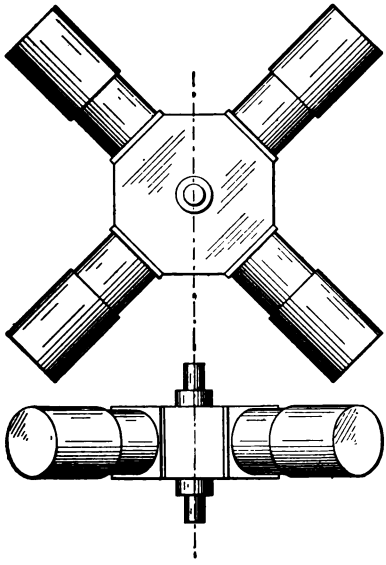

Fig. 6. Four-Cylinder Star Type

A modification of Fig. 4 is illustrated in Fig. 6, which shows a four-cylinder radial motor. In practice, however, four is not a good number for this type, as the impulses can not be evenly divided, which accounts for the general use of an odd number of cylinders in a radial arrangement. Such a motor can be satisfactorily balanced where the cylinders are evenly spaced about the circumference of the crank case, as all the connecting rods are attached to a common crank pin, and, therefore, form one revolving mass, which can be balanced by a suitable balance weight. But as

the number of cylinders increases, the difficulty arises of attaching all the big ends of the connecting rod to one crank pin, without making the ends of the connecting rods unusually narrow or the pin itself over long. This is obviated by the arrangement shown in Fig. 118, one connecting rod, the upper one in the sketch, being formed with a disk to which the others are attached by means of bosses, or short pins.

In balance, this engine is naturally superior to either of the arrangements shown in Figs. 4 and 5. In the case of Fig. 4, the placing of all the cylinders on top of the crank case makes it impossible to divide the impulses evenly, and this motor has to be built with heavy inside flywheels, similar to a motorcycle engine. With this addition, such a motor runs well, but it is a question whether the advantage of greater accessibility gained by placing the cylinders in this position, is not more than offset by the extra weight of the flywheels that could be saved by disposing the cylinders equidistant around the crank case, so that the impulses would come 120 degrees apart.

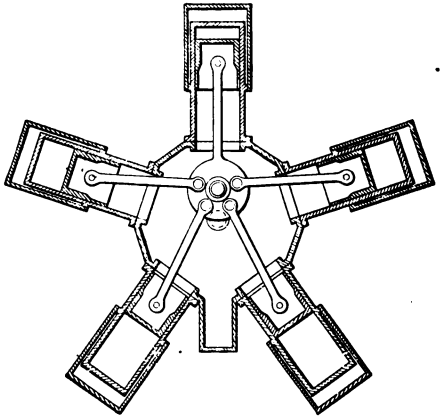

Fig. 7. Five-Cylinder Radial or Star Type

Fig. 5 is really a five-cylinder radial engine with the two cylinders shown below in Fig. 7 placed on top of the crank case. In this case, three of the pistons actuate one crank and the remaining two another, the cranks themselves being opposed or 180 degrees apart. The division of the impulses is the same as in the complete radial engine, Fig. 7, and the balancing almost as good, but the crank shaft has to be of a larger diameter owing to its weaker form, and as both it and the crank case are longer, there will be an increase in the weight. Take Fig. 7 and assume that its crank shaft is held stationary, and we have the usual revolving type of radial motor which has proven so successful in service. It does not require any great amount of study to show that whether the cylinders revolve

or remain stationary, the total weight of the motor will be the same, assuming the accessories and fittings in each case to be similar. This being the case, the only manner in which the revolving cylinders can be of any advantage is either to make the crank case and the cylinders themselves lighter, or to obtain more power for the same sized cylinder when revolved.

The chief advantages of the revolving motor are that it dispenses with a flywheel and makes air cooling more positive. Under the conditions obtaining on an aeroplane soaring at any considerable height, it may be questioned whether this is not really too much so, the great reduction in the temperature of the motor very unfavorably affecting its efficiency and unduly increasing its fuel consumption. That this is quite likely to be the case will be apparent from the fact that in a revolving motor in which the ends of the cylinders are 15 inches from the crank shaft, the former will be moving through the air at 95 miles an hour when the motor is running at 1,200 r. p. m. In practice, the power obtained per cubic inch of cylinder capacity from the Gnome motor is small, and it seems quite probable that the same power could be obtained by employing fixed cylinders of smaller dimensions. That it is extremely light for its size will be seen from its weight of but 0.35 pound per cubic inch of cylinder capacity, but this is undoubtedly due to the high-grade materials used and the methods of machining employed in its construction.

Another point of importance in the comparison of these various arrangements that is quite as vital as that of weight, or will be as soon as durability in an aeroplane motor is given proper consideration, is their effect on the bearings. By grouping the cylinders the crank case is shortened but the work put on the bearings is increased, without, in most cases, any proportionate increase in the amount of bearing surface. For instance, in the diagonal or V-type, each main bearing has to take the load of two cylinders, instead of one. This is aggravated still further by placing three cylinders on top of the crank case and in the radial type matters are still worse, though in the latter, various expedients to overcome this, such as that illustrated by Fig. 7, are adopted.

The difficulty of lubricating the radial type of engine has already been mentioned and need not be repeated here. Just how each maker has solved this extremely important part of the problem of his design,

will be referred to in connection with the descriptions of a number of prominent American and European aeronautical motors that follow.

AMERICAN MOTOR TYPES

Wright. As the Wright motor was the first to leave the ground in a man-controlled aeroplane, it is natural that it should be given prominence in this connection. When the Wright Brothers attacked the problem of using power for their flights they searched the market for a suitable motor but were unable to find anything that met their requirements. It will be recalled that the automobile motor was not a very highly developed power unit in 1902. They were accordingly compelled to develop a design by study and experiment, as in the case of the aeroplane and the propellers. The result is an exceedingly simple and efficient motor of the four-cycle type which at first glance resembles the present-day automobile motor of light cars, particularly since the practice of making an oil tank an integral part of the crank case has come into vogue. The Wright motor is of the four-cycle type, the cylinders being cast independently of gray iron, while the crank case, of unusual depth, is of aluminum alloy, as are also the water jackets of the cylinders. The exhaust valves are in cages opening directly to the air and are operated by means of rocker arms, as they are placed in the head, alongside of the automatic inlet valves. The crank shaft is of nickel steel and in accordance with the practice that obtained in the automobile field seven or eight years ago, it is *whittled* out of a solid block, the cam shaft also being machined from the bar in the same manner. Oil is carried in a special tank forming the bottom of the 1-piece crank-case casting, lubrication being insured by a small gear type of pump driven from the cam shaft. A second small gear pump driven in the same manner and located beside the oil pump, shown in the illustration of the right side of the motor, Fig. 8, is for the purpose of supplying the fuel to the engine, a carbureter being dispensed with in view of the extreme variations of altitude under which the motor must operate. As will be apparent from the photo, this pump delivers the gasoline direct to a mixing chamber located at an elbow of the intake manifold, the end of which is open to the air. An injector controls the amount of gasoline supplied to

each cylinder in direct proportion to the speed of the engine. By comparison with the highly developed type of carbureter now employed on the automobile, this device appears to be a reversion to the old stationary engine type of mixer, but it must be borne in mind that an aeroplane motor constantly operates at its normal or even maximum output, so that provision which would be totally

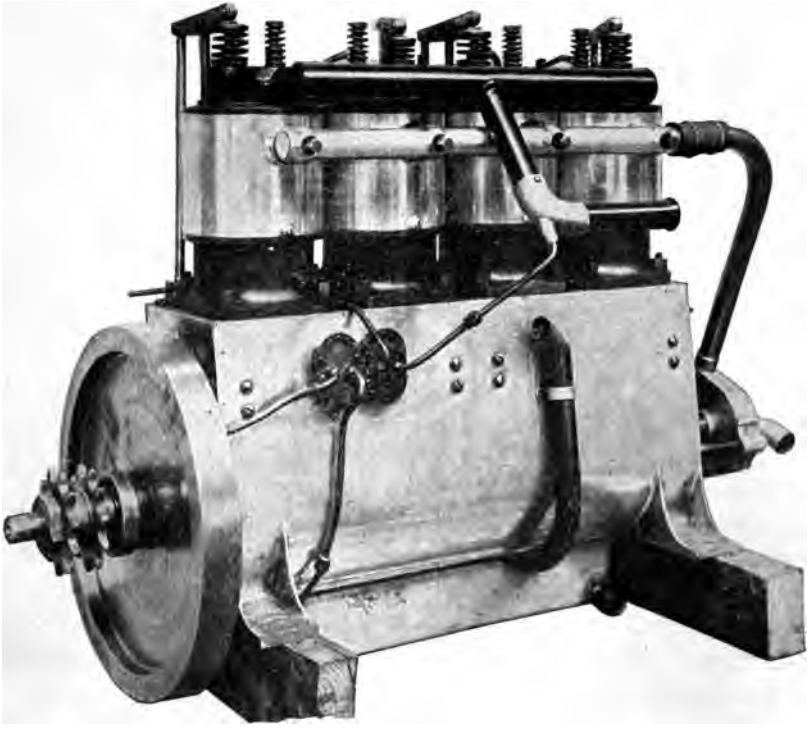

Fig. 8. Right Side of Wright Four-Cylinder Aeronautical Motor

unsuited to automobile use in view of the demand for the greatest possible range of speed and power output, is undoubtedly far more reliable under such ideal conditions of operation.

Ignition is provided by a "Mea" high-tension magneto driven by a two to one gear on the end of the cam shaft but outside of the crank case, the magneto being set on a bed cast integral with the latter. In this type of magneto, the entire field magnet is arranged to oscillate about the armature, so that regardless of the position of "advance" or "retard" for which the spark control is set, the spark

always occurs at what is known as the "peak of the curve," *i. e.*, the point of greatest current flux, giving a spark of the maximum value for ignition purposes. The cooling water is circulated by means of a centrifugal pump attached directly to the end of the crank shaft, as shown by the view of the left side of the motor, Fig. 9, which also illustrates the magneto and its drive. The radiator consists of a small group of flat, vertical, copper tubes, several feet in

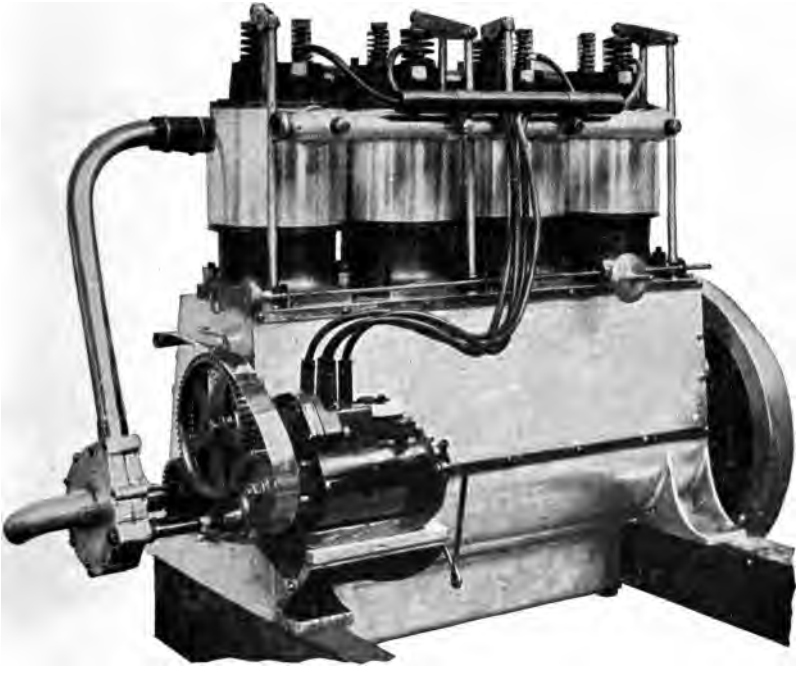

Fig. 9. Left Side of Wright Four-Cylinder Motor Showing Magneto and Its Drive

height, and with small aluminum headers at each end. Unlike many designers of aeronautic motors, the Wright Brothers have not attempted to reduce weight at the expense of safety, as will be very apparent from the liberal flywheel provided. Where not more than four cylinders are employed, there is no single feature that adds so greatly to the reliability of a motor and the uniform delivery of its power output, as a flywheel of ample weight. This essential is of web pattern and is of cast iron, instead of the usual spoked wheel commonly employed. The cylinder dimensions are $4\frac{3}{8}$-inch bore

by 4-inch stroke, the power output being 30 to 35 horse-power at about 1,200 r. p. m. The total weight, not including the radiator or water supply, is 180 pounds, or 5½ to 6 pounds per horse-power, which is very high as compared with the weights of the majority of aeronautic motors. The power is transmitted to the propellers through the two sprockets shown on the crank shaft at the flywheel end, and nickel steel roller chains, one of the latter being crossed to reverse the motion of its screw. The propeller shafts are of chrome nickel steel and are carried on annular ball-bearings. The high

Fig. 10. Complete Power Plant and Transmission of Wright "Baby" Biplane

degree of reliability shown by the Wright motor in service affords a striking illustration of the fact that extremely light weight is far from being the chief thing to be desired in an aeroplane motor. For the "baby" Wright machine and the "racer," an eight-cylinder, V-type motor, Fig. 10, which is characterized throughout by the same features of design, is employed. This is rated at 60 horse-power, and is designed to drive the propellers at a much higher rate of speed than in the standard machine in which they turn at 400 r. p. m.

Curtiss. On the early Curtiss aeroplanes, a four-cylinder, vertical, four-cycle, air-cooled motor, which was practically the same in most respects as the standard automobile type, was employed.

This developed about 25 horse-power. It soon gave way, however, to an eight-cylinder, V-type motor of the same general design rated at 50 horse-power, and it has been with this motor that Curtiss has made all of his flights of note. The new Curtiss racer is provided with a water-cooled motor, Fig. 11, something which serves to accentuate the difference in the conditions between land and air travel. It would appear that in view of the high wind blowing on the motor and the low temperature of the air blast, that air cooling

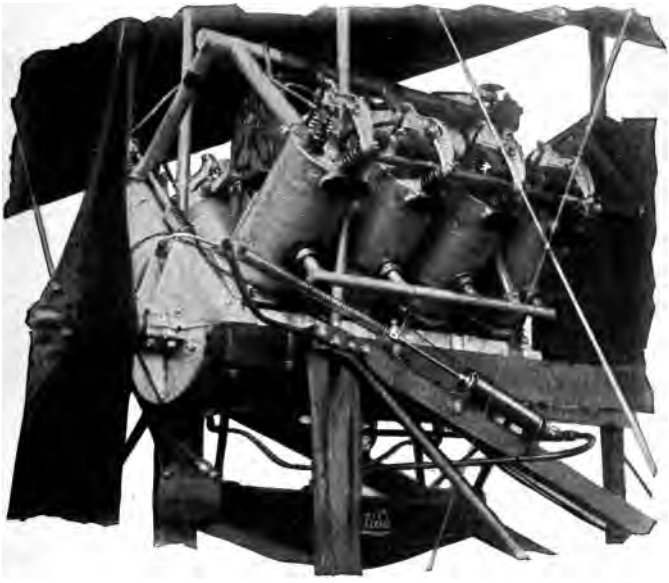

Fig. 11. Curtiss Water-Cooled V-Type Motor

would present no difficulties whatever. As already mentioned, however, an aeroplane motor operates constantly under full-load conditions, and the rear cylinders of a longitudinally-arranged motor are apt to become overheated despite the constant supply of cold air blowing on them. This, in addition to involving the risk of stopping the motor without warning, also cuts down the power of these cylinders due to the rarefaction of the fuel mixture at a high temperature, makes lubrication difficult, and greatly increases the consumption of lubricating oil. Tabuteau's 8-hour flight in France with a Renault air-cooled motor shows the efficiency of air-blast cooling.

The amazing rapidity with which aviation has progressed dur-

ing the past few years has been responsible for the entrance of a number of motor manufacturers into the field, many of whom are already building automobile or marine motors, while others undertook the making of special aeronautic motors from the start. As is naturally to be expected, the majority of the motors turned out by the former class are more or less conventional in their design, though distinguished by special features in some instances, yet not as a whole of sufficient interest to merit detailed description of more than a few that may be regarded as representative of a class.

Four-Cylinder Water-Cooled Type. The first of these is the four-cylinder four-cycle vertical water-cooled motor. This, in brief, is nothing more nor less than a light type of automobile motor, and in some cases no great attempt has been made at weight-saving, as there are several in which the water jackets are of cast iron, integral with the cylinders as in automobile practice.

Harriman. In the Harriman, these were at first replaced by copper jackets and more recently by light sheet-steel jackets autogenously welded in place, thus insuring against leakage. A novel feature of this motor is the fact that the lower ends of the cylinders are threaded and screw directly into the crank case and lock, the usual flange and bolt fastening being done away with. Both valves are placed side by side in the head and are operated by a superimposed cam shaft placed between them and driven by a vertical shaft and bevel gears from the crank shaft. The same cam operates both the inlet and exhaust valve in each case. The water jacket of the cylinder head, and the valve ports are cast with the cylinder, the jacket of the barrel being of sheet steel as mentioned. An auxiliary exhaust port in the form of a series of holes drilled in the cylinder castings and uncovered by the piston at the lowest point of its stroke aids in quickly scavenging the cylinders. The Harriman is one of the few aviation motors on which the option of battery ignition is offered, the Atwater-Kent system being employed. These motors are built in two sizes, 30 and 50 horse-power and are designed to run at 1,400 r. p. m. Their weight is four pounds per horse-power.

Horizontal-Opposed Type. On one hand there has been a demand for a simpler and lighter motor to give the same power as the type just mentioned, and on the other for greatly increased power. The former has been met by the horizontal-opposed type.

Detroit Aero. An example of this is the Detroit Aero, which with cylinders of 5½-inch bore by 5-inch stroke is rated 25 to 30 horse-power at 1,500 r. p. m. The valves are located in the head and actuated by tappet rods and rocker arms. Cooling is by air direct, the arrangement of the cylinders lending itself with great advantage to this. Quite a number of this type of motor are now being used

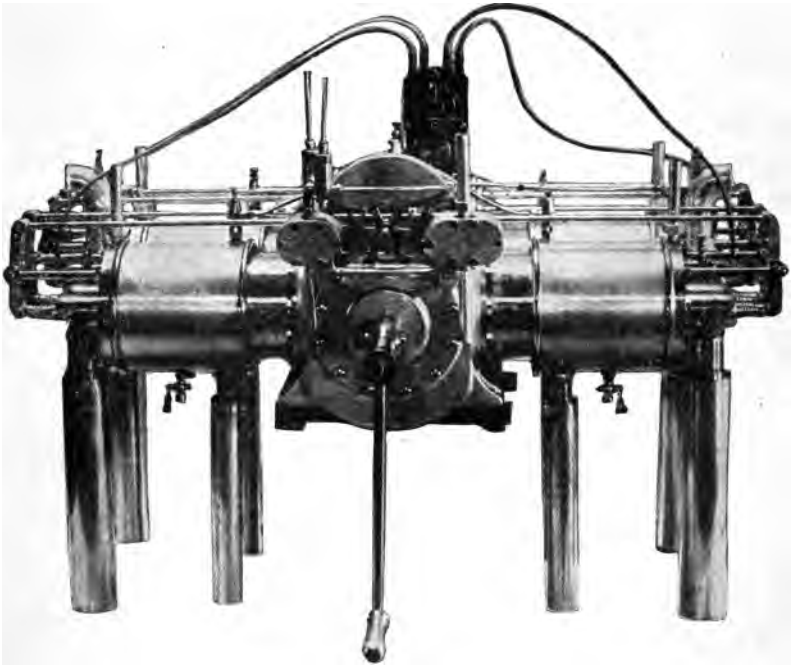

Fig. 12. Call Aviation Motor Fitted with Mufflers

in France where they were never regarded favorably for automobile work.

Call. A specially-designed horizontal-opposed type is the Call aviation engine, Fig. 12. This has four cylinders opposed in two pairs, the dimensions being, bore 6 inches, stroke 5¼ inches, and rated at 90 horse-power. It is also built as a two-cylinder opposed rated at 45 horse-power. The cylinders are of a vanadium alloy iron, machined inside and outside and pressed into magnalium (a very strong and light aluminum alloy) water jackets. To save weight, the cylinders are cast of the usual thickness at the combustion cham-

ber, extending down as far as the stroke of the piston, and from there on to the crank case are only half as thick. It is claimed that this construction in connection with the unusually light jackets gives a weight per horse-power equal to that for the cylinders of the customary construction. Ribs extend inwardly from the magnalium jacket and press tightly against the machined outer surface of the cylinder, thus reinforcing the combustion chamber. The cylinder heads are of the same construction as the cylinders, the main portion

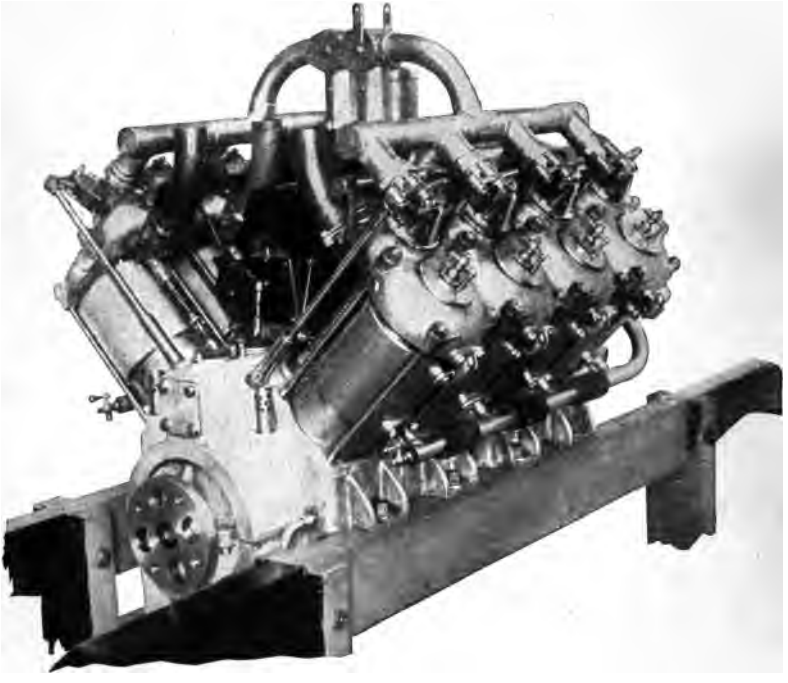

Fig. 13. 65-Horse-Power Indian Aeromotor, Hendee Manufacturing Company

being of magnalium which is lined with a circular plate of iron over the combustion chamber. Both valves are mechanically operated and are in cages in the head. The valve seats are water cooled while the cages are air cooled to save weight. These cages are cast very thin and have cooling flanges to protect the valve stem bearings. The pistons, cast of the same iron as the cylinders, are provided with internal cooling flanges on the heads. Magnalium is also employed for casting the crank case, numerous internal ribs amply reinforcing it. Lubrication is by the splash system, the supply being

maintained by individual oilers in the form of large cups on the tops of the cylinders. A quick exhaust is insured by the use of large valves with a full lift of approximately one-fourth the valve diameter, supplemented by auxiliary exhaust ports at the end of the stroke. The Call engine is the first aeronautical motor to be fitted with a muffler. Silencers of special design without the usual tubes or baffle plates are fitted directly to the exhaust valves and auxiliary exhaust ports of every cylinder, extending straight downward. The weight of the 45-horse-power motor is 135 pounds, and of the 90-horse-power type, 225 pounds, or 3 and 2.5 pounds per horse-power, respectively.

Fig. 14. Hamilton Eight-Cylinder V-Type Motor

Eight-Cylinder V-Type. *Hendee.* The Hendee aviation motor may be cited as an example of the eight-cylinder V-type, Fig. 13. No attempt has been made to achieve extreme lightness, the object being rather to provide a motor that will carry full load for long periods. The cylinders and heads are cast separately, the former having a light brass water jacket spun into grooves and the joint brazed. The heads have separate jackets connected to the cylinder jackets by a flexible joint. Both valves are placed in an out-board port on the inner sides of the cylinders, the inlet valve being placed

on top and operated by a rocker arm while the exhaust is operated direct. The inlet valve is carried in a cage held in place by a breech-block lock; its removal exposes the exhaust valve and permits its withdrawal. The cylinder dimensions are 4-inch bore by 4½-inch stroke, the output being 60 to 65 horse-power, and the weight 260 pounds, or 4.3 pounds per horse-power. Curtiss used one of these motors in the long-distance flights at the Harvard Aviation Meet.

Hamilton. The Hamilton motor, Fig. 14, is of the conventional eight-cylinder V-type, but is distinguished by an unusual valve operating mechanism most of the details of which will be apparent from the photograph. Both valves are placed in the cylinder heads, and the entire valve-operating mechanism is superimposed on them. The vertical tube visible in the foreground between the cylinders is a crank-case "breather" or vent.

Two-Cycle Motors. *Roberts.* As already mentioned, the aeroplane affords an excellent field for the two-cycle motor in view of the constant power requirements, similar to the condition obtaining in marine work. A representative motor of this type is the Roberts, designed by E. W. Roberts, whose experience in the field of aviation dates back to 1894 and 1895 when he served as assistant to Hiram S. Maxim in his experiments at that time. The Roberts two-cycle aviation motor is of the customary three-port type except that instead of opening the admission and exhaust by means of the piston, a special tubular rotary valve is employed, it being claimed that this effects better control of the opening to the crank case and greater economy. The cellular by-pass fitted to Roberts marine motors is also employed to prevent back firing or explosions in the crank case. The cylinders are of hardened steel, their dimensions being 4½-inch bore by 5-inch stroke. Part of the water jacket is cored out of the cylinder casting while the remainder is covered with an aluminum jacket caulked into a groove in the cylinder itself. The pistons and rings are of cast iron and the crank case of magnalium. Ignition is by means of a Bosch magneto with a special advance device as it is impractical to operate the two-cycle motor with a fixed ignition point, it being necessary to retard the explosion timing considerably in order to start without danger of the motor kicking back. To effect this a helical gear is employed to turn the armature of the magneto with relation to the drive. The four-cylinder Roberts

motor with carbureter and magneto weighs 165 pounds and develops 52 horse-power at 1,400 r. p. m., while the six-cylinder weighs 220 pounds and develops 78 horse-power at 1,500 r. p. m,. or 3.17 and 2.8 pounds per horse-power, respectively.

Fox. The Fox aero motor is another two-cycle type that is distinguished by the use of a special fourth port. Apart from this, the motor is of practically the conventional three-port type. This fourth port, known as an *accelerator*, is an opening placed below the third port and is designed to admit air alone, which goes through a by-pass on the side of the cylinder, where the fourth port is uncovered by the upward stroke of the piston immediately after the opening of the third port. The incoming fuel charge through the latter is deflected toward the bottom of the crank case, while the air entering through the fourth part is deflected upward and is pocketed under the piston until the opening of the intake port, entering the explosion chamber in advance of the fuel charge. It accordingly serves to drive out the exploded gases in advance of the entrance of the fresh fuel, thus increasing the power and making the motor more economical. The external opening of this fourth port is directly controlled by the operator through a lever, so that it may be closed entirely, when the motor will operate as the usual three-port type; or it may be opened full when greater speed and power are required, which accounts for the name given it. These motors are built in sizes ranging from 36 horse-power, weighing 150 pounds, up to 200 horse-power, weighing 850 pounds, the cylinder dimensions of the smallest size (four cylinders) being $3\frac{1}{2}$ by $3\frac{1}{2}$ inches, and the largest (eight cylinders) 6×6 inches, the average weight per horse-power being about 4 pounds. The cylinders are placed in line in all the sizes.

Elbridge. A two-cycle motor with which a number of successful flights were made by amateur aviators during 1910, is the Elbridge aero special. This is a four-cylinder, vertical, three-port type and it is claimed by the makers that it will carry almost its maximum load up to as high a speed as 2,000 r. p. m. Without the magneto it weighs slightly less than 150 pounds and delivers 50 to 60 horse-power.

Rotary Type. *Adams-Farwell.* The Adams-Farwell, Fig. 15, which is the prototype in this field, was first used for automobiles

in 1898 and has recently been redesigned for aviation purposes. In some respects this motor is very similar to the five-cylinder revolving motors used in the Adams-Farwell automobile, having the same number of cylinders, the same single throw crank, the same positive oiler, and the same crank construction. In other respects, however, it is quite different, being designed solely for aviation purposes, and revolving in a vertical plane, so that it may be direct connected to propeller shaft or have the propeller mounted directly upon the motor for aeroplane work.

The most interesting improvement found on this motor and, no

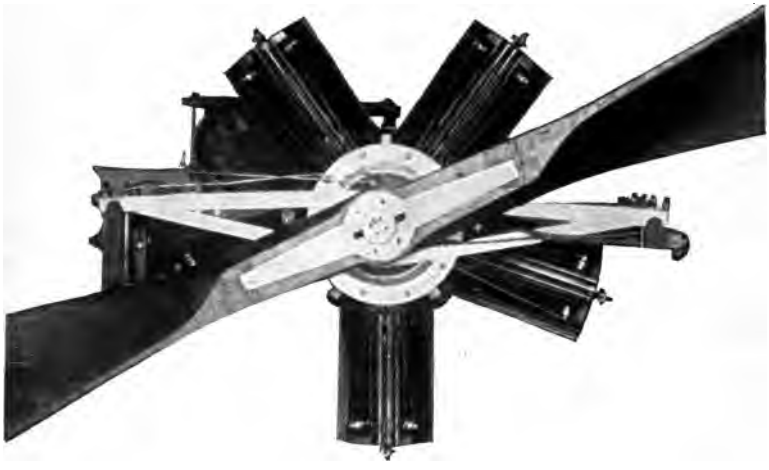

Fig. 15. Adams-Farwell Revolving Aeronautical Motor

doubt, the most important advance made in the construction of aviation motors since the introduction of the revolving cylinder type, is the elimination of the carbureter and employment of fuel injection with a means for regulating the amount of gasoline injected into each cylinder, and insuring that all cylinders will receive exactly the same mixture. This also makes it possible to do away with the inlet valve, and employ one valve for both inlet and exhaust, as only air is drawn in by the suction stroke of the piston, while the gasoline is sprayed within the cylinder where it is mixed with the charge of air before compression. Having but one valve in the head of the cylinder it can be made amply large to insure a full charge and a free exhaust.

In order to relieve the cam controlling the action of all five valves from the heavy load of opening a large valve against the high pressure at the time exhaust takes place, the cylinders are provided with auxiliary exhaust ports, which are uncovered by the piston on its downward stroke. No check valves are required over these auxiliary ports, as, on the suction stroke, pure air and not a mixture of gas is drawn in, so what air is drawn in through the auxiliary ports on the suction stroke becomes a part of the explosive mixture in the cylinder, and being a constant quantity does not affect the operation of the motor.

The control of the motor is entirely taken care of by regulating the amount of gasoline used, and the only adjustment that might be construed as belonging to the carburetion system, is the valve by means of which this control is accomplished. The motor is not sensitive to adjustment, and the speed may be regulated through quite a wide range by this simple means.

The lubrication system mentioned consists of a simple and ingenious oiling device that is a patented feature of the motor and represents a great advance over the present wasteful method of lubricating rotary motors. This oiler consists of a single rotary member much resembling in form the cylinder of a revolver, with longitudinal chambers bored therein. Each of these chambers carries a plunger which, as the cylinder revolves, is driven from end to end by two stationary cams, causing a small amount of oil to be drawn in to each of the chambers at the bottom and ejected into a corresponding tube at the top. This oiler supplies cylinder oil of an extra heavy grade to the various bearings and to the cylinders, doing away with the necessity for splash lubrication, which calls for the flooding of other revolving cylinder motors with a great quantity of oil that dirties the valves and soots up the spark plugs.

There are two spark plugs in each cylinder of this motor, and two independent ignition systems are employed, so that either or both of the set of plugs may be used, thus insuring against the accidental stoppage of the motor from a broken wire.

Something over ten years ago, the Adams Company conducted a series of experiments to determine the action of the air in circulating about the cylinder of a revolving cylinder motor, and, as a result, established beyond question the fact that longitudinal ribs are much

more efficient than the circular type. The air coming in contact with the cylinder walls is thrown off radially, circulating lengthwise of the cylinders, so the only logical arrangement of cooling ribs is lengthwise of the cylinders. The placing of ribs in this way has the further advantage of strengthening the cylinder against tensile strain caused by the action of centrifugal force, and the explosion.

This new motor operates satisfactorily on low-grade fuels, but when these grades are employed, it is desirable to have a small tank of gasoline of higher specific gravity to facilitate starting. Reliability has been considered above extreme light weight, as evidenced by the large connecting-rod bearings, the liberal size of the crank shaft, and the fact that four rings are employed on the piston where some builders of aviation motors are using only a single ring. Vanadium chrome nickel steel is used wherever practicable. The dimensions are 6-inch bore and stroke, and at 1,000 r. p. m. the motor is rated at 72 horse-power. It drives a 9-foot 6-inch propeller of 6-foot pitch at 900 to 1,000 r. p. m., developing a thrust of 440 to 460 pounds, which can be maintained indefinitely without overheating the motor.

Brooke "Non-Gyro" Motor. This is another American motor of the rotary type of recent development. It is made in Chicago and is distinguished by several new features that should make it of value for aeronautical purposes, and particularly for aeroplane work. The Type "E" Brooke motor, which lists at $2,500, has 10 cylinders, arranged in two units of five each, either of which may be run independently of the other when desired. With all 10 cylinders working, the motor is rated at 85 horse-power. The cylinders are offset slightly on the crank case and measure $4\frac{1}{4}$ by $4\frac{1}{4}$ inches. Two Stromberg carbureters are employed, one for each unit, while a two-cylinder type of magneto takes care of the ignition of all 10 cylinders, there being but one foot of high-tension cable necessary and no moving contacts, making a very simple and positive ignition system that should prove of great value, as the ignition is a weak point in even the best of motors and its failure through trivial causes is hard to guard against where a number of small parts and a great deal of wiring is necessary. Another improvement is the elimination of the wasteful method of "shooting" oil through the motor for lubrication, as in the Gnome, a nine-tube, force-feed oiler being employed instead. The intake valves are placed in the piston heads, while the exhaust

valves are in the cylinder heads. Light springs are used to keep the valves in place when the motor is idle, but they have no function to perform when it is in operation.

Weinberg. An interesting development of this kind is the Weinberg, two-cylinder, horizontal-opposed, air-cooled motor, a Detroit product. The crank shaft is stationary while the cylinders revolve about it, centrifugal force being taken advantage of to draw in the charge through the hollow shaft and to exhaust it. During the outward stroke of the pistons a vacuum is created in the crank case, drawing in the mixture of fuel and lubricating oil, a check valve between the carbureter and crank case preventing its escape on the return stroke. When the piston reaches the lower limit of its stroke, the charge enters the combustion chamber through a by-pass, the motor accordingly being in reality a two-cycle type with an independent exhaust valve. The latter is mechanically opened by means of a rocker arm. This valve is located in the cylinder head and is very large—almost two-thirds the cylinder diameter. Centrifugal force keeps it closed between explosions so that no valve spring is required. The cylinders and pistons are cast iron machined all over, while the crank case is a one-piece casting of aluminum alloy. The magneto is gear driven at the same speed at which the cylinders revolve, the current being distributed to the spark plugs through a revolving sector. Both cylinders fire simultaneously.

Metz. The Metz is a four-cycle, seven-cylinder revolving motor of unusually large size, Fig. 16, the cylinders having a bore and stroke of $6\frac{3}{4}$ inches. It develops 125 horse-power at 800 r. p. m. and weighs 375 pounds, or exactly 3 pounds per horse-power. The cylinders are of chrome steel machined direct from hollow forgings with very thin integral flanges for air cooling. They are attached to a drum-shaped crank case cast of alvanum, another aluminum alloy of great strength and lightness, mounted on large annular ball bearings. The stationary crank shaft and crank pin are of chrome nickel steel. Both valves are placed in the cylinder heads and are mechanically operated. The valves themselves are nickel steel while the push rods for operating them are light tubes of the same metal. Instead of feeding the mixture up through the pistons as in the Gnome revolving motor, it is led from the crank case to each of the inlet valves through light copper pipes. The fuel and lubricating oil enter the crank case

through the hollow crank shaft, centrifugal force being relied upon to distribute the lubricant. The pistons are very light and are fitted with a novel type of floating piston ring.

Weight per Horse-Power Hour. It will be noted that in very few of the cases mentioned does the weight of the motor exceed four

Fig. 16. Metz Seven-Cylinder Revolving Motor with Nickel-Steel Cylinders

pounds per horse-power; in the majority it is between two and a fraction of this figure, or say an average of three pounds. This, of course, refers to the motor alone; in the case of water-cooled motors the addition of the radiator, water supply, gasoline tank, and similar fittings will usually increase the weight by almost a pound per horse-power. Even at that it will be evident that improvements in construction and a disregard for the cost of the finished product have accomplished wonders where the reduction of the weight is concerned. It is not too much to say that even the heaviest of the

motors in question is a remarkably light power unit. But there is a factor that is of greater importance in the result than that of the weight per horse-power. This is the weight per horse-power hour as explained in Dirigible Balloons, page 25.

FOREIGN MOTOR TYPES

As with the automobile, the French took up the aeroplane and its motive power with all the energy and enthusiasm they possess, right from the start. Even before the Wrights made their first public flights in France, interest was widespread and much had been accomplished. The same spirit was not infused into the art on this side of the Atlantic until 1910 and even then the number

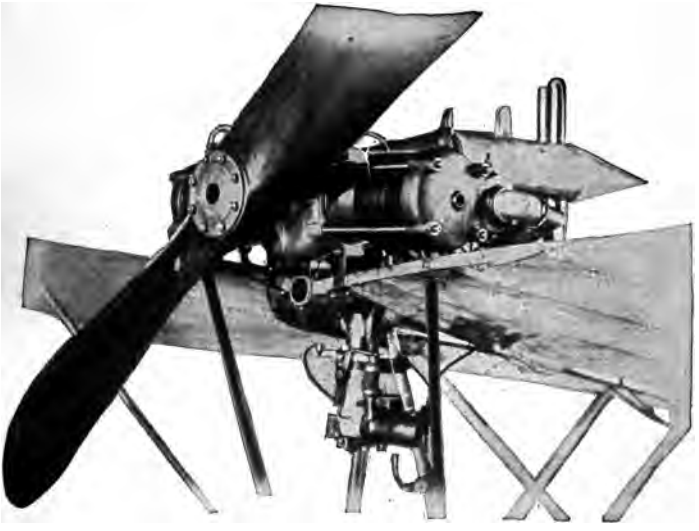

Fig. 17. Deuthil-Chalmers Two-Cylinder Air-Cooled Motor

of investigators devoting their attention to it, the number of machines in existence, and the number of men who could actually fly, were but a small fraction of those engaged in the pursuit of aviation in France. This briefly explains why so much attention has been devoted to the development of the aeroplane motor abroad, as shown by the following examples, the majority of which are of French construction.

Horizontal-Opposed Type. *Deuthil-Chalmers.* There is, however, an American *note* in this development, if it may be so called, and that is the adoption of the two-cylinder, horizontal-opposed

motor—a purely American type—for very light units. The best representative of this class is the Deuthil-Chalmers 20-horse-power, air-cooled motor used to drive Santos-Dumont's Demoiselle. Following the precedent of so many other makers, later models of this motor are water cooled, Fig. 17. The first air-cooled, two-cylinder type weighed but 48.5 pounds, or $2\frac{1}{2}$ to $2\frac{3}{4}$ pounds per horse-power, while the later model, and particularly the four-cylinder type, weighs 4 pounds per horse-power. The connecting rods of each pair of cylinders are attached to a common crank, while instead of the usual fly-wheel, a wire spoke wheel resembling bicycle construction, is employed. Cylindrical valves, both of which are mechanically operated, are placed in the heads, the cylinders being attached to the drum-shaped

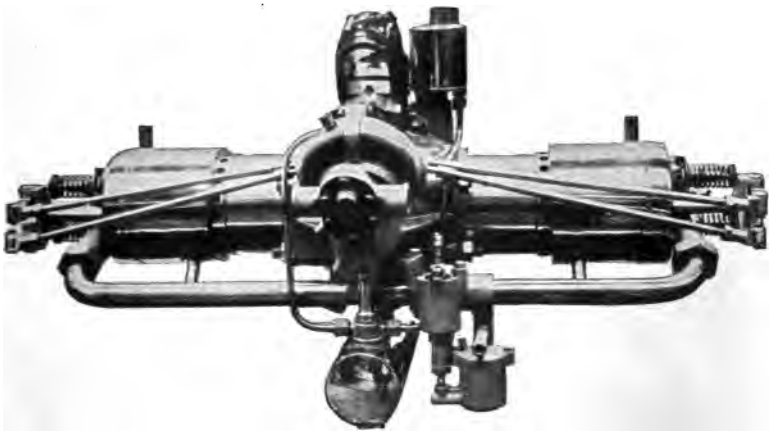

Fig. 18. Darracq Two-Cylinder Motor

crank case by means of long stay rods which pass through clamps over the cylindrical heads. The spark plugs are placed in the upper sides of the heads with the water outlets close to them, the water intake being on the under side. Special oil feeds are run to the cylinders to lubricate the pistons, splash not being depended upon for this purpose. The complete motor is attached to the aeroplane by two bolts passing through lugs cast in the crank case.

Darracq. Another motor of this type is the Darracq, shown in Fig. 18. This is also a water-cooled motor, most of the constructional details of which are apparent in the photograph. Both valves are mechanically operated by rocker arms and push rods actuated

by a pair of eccentrics completely housed in, this being a distinction from the general practice in aviation motors, the timing gears usually being exposed as in the original automobile motors. The magneto is mounted at an angle on top of the crank case, while both the carbureter and the oil tank are suspended below it, a pump immersed in the tank itself distributing the lubricant.

Clement. In the Clement motor of this type, both the oil and water tanks are combined and are mounted over the crank case,

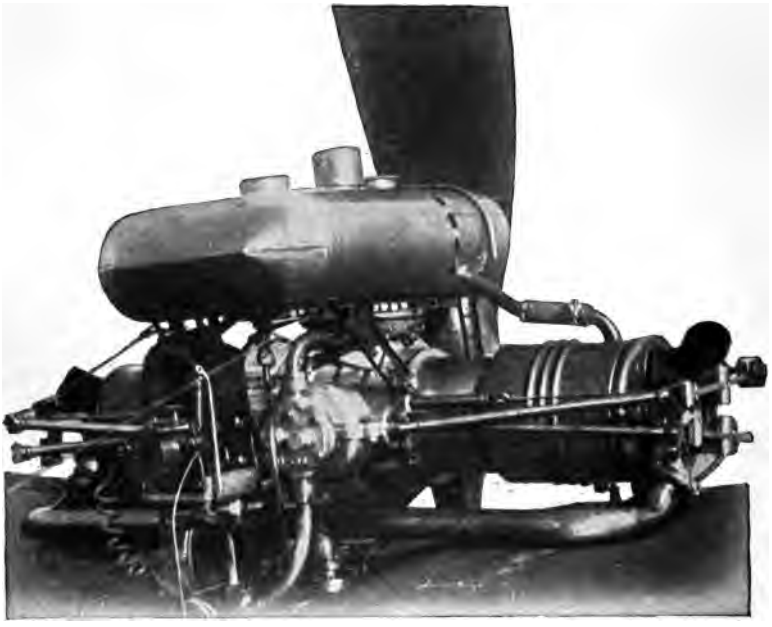

Fig. 19. Clement Two-Cylinder Water-Cooled Motor

as shown by Fig. 19. A similar valve action and arrangement of the carbureter and intake piping are employed as in the Darracq, while the magneto is mounted alongside the gear type water pump at the back of the motor.

The next class in what may be termed the order of development is the conventional four-cylinder vertical type, many of which, however, are distinguished by unusual features.

Conventional Four-Cylinder Type. *Wright-Barriquand.* Of the more conventional types, the Wright-Barriquand (French Wright

motor) differs from its American prototype only in slight detail, the principal feature being the use of mechanically-operated inlet valves. (See Fig. 20.)

Panhard and Primi-Berthand. The Panhard and Primi-Berthand, Figs. 21 and 22, are similar in so far as their cooling arrange-

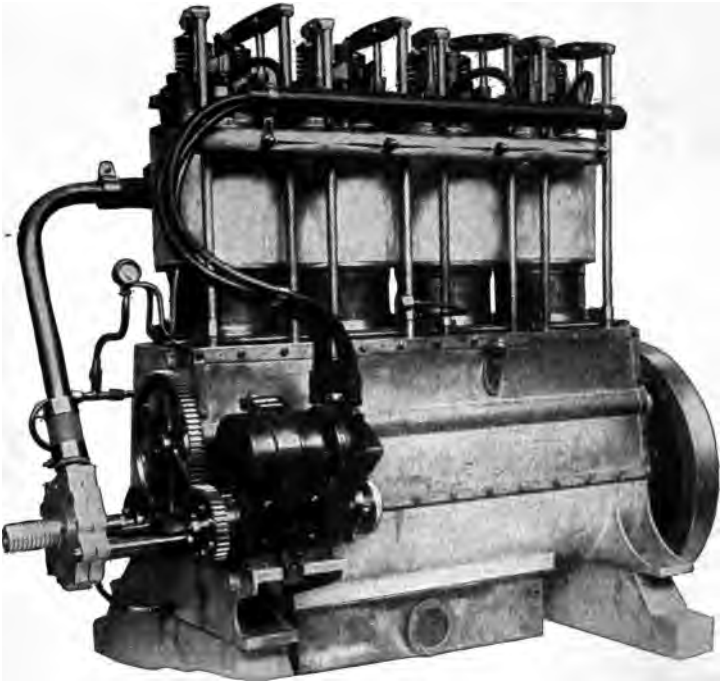

Fig. 20. Wright-Barriquand (French Wright) Motor

ments are concerned. That is, both have light sheet-copper jackets of corrugated section to increase the radiating surface. But the former is a four-cycle type with the valves in the head operated by rocker arms, while the latter is a two-cycle engine, as will be apparent from the photo, which illustrates the carbureter and the method of drawing the fuel mixture into two outside chambers, which communicate with the cylinders through the ports shown, these being opened by the pistons at the lower end of the stroke.

Vivinus. The Vivinus, Fig. 23, is another aviation motor that has been directly developed from the automobile type of the same make. No attempt has been made to achieve lightness, the

motor weighing 300 pounds for an output of only 50 horse-power, or 6 pounds per horse-power. But trials have shown it to be capable of sustained operation without power losses, it having been employed successfully on a Farman biplane in England. As the illustration shows, a pressed-steel flywheel is employed.

Fig. 21. Panhard Aviation Motor

Other Vertical Cylinder Types. Motors of a generally similar type, the chief features of which are evident from the illustrations, are the De Dietrich, Fig. 24; M. A. B., Fig. 25; Aster, Fig. 26, and the Buchet six-cylinder, which is shown mounted on the framing of a Bleriot monoplane in Fig. 27. It will be noted that the propeller in this case is depended upon to take the place of the flywheel. Practice shows this to be permissible when six or more cylin-

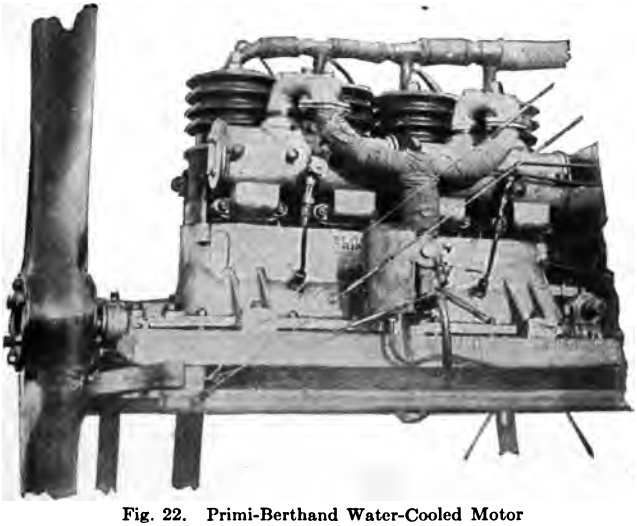

Fig. 22. Primi-Berthand Water-Cooled Motor

ders are employed, although its omission is not infrequent even on a four-cylinder motor, as will be noted by reference to the Gregoire,

mentioned farther along. The flywheel also has been eliminated even when no more than two cylinders are employed as in the Deuthil-Chalmers horizontal-opposed type already described. To say the least, it is not good engineering practice, particularly in two- and four-

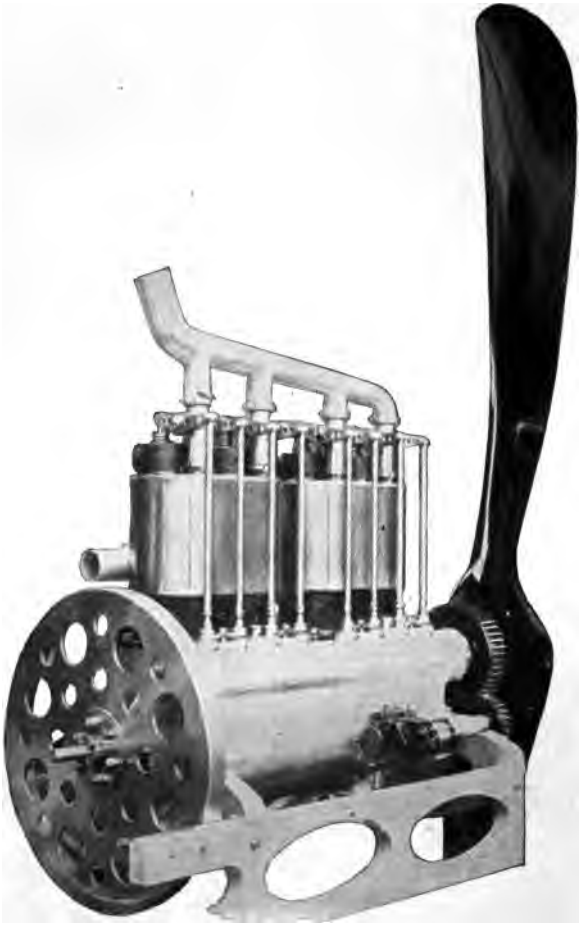

Fig. 23. Vivinus Aviation Motor

cylinder types, as there is a well-defined interval between the impulses in both of these. In the six- and eight-cylinder types in which the impulses always overlap, giving a continuous torque, even the slight weight of the wood propeller blades revolving at such a great distance from the hub is sufficient to compensate for the lack of a flywheel,

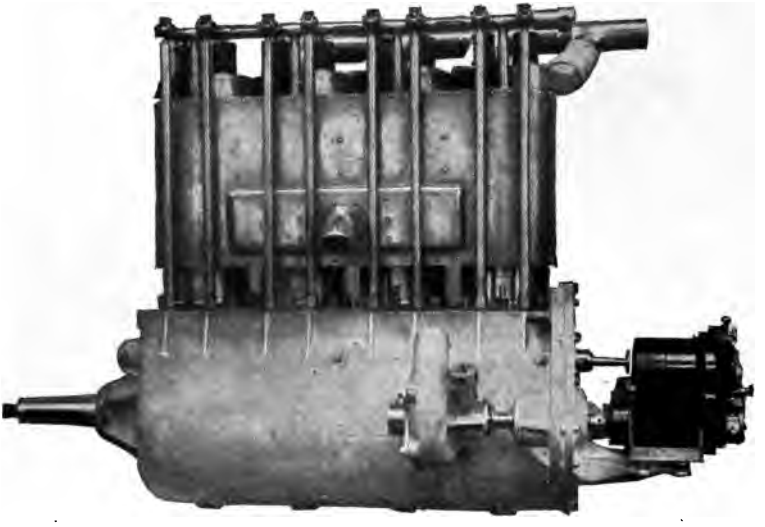

Fig. 24. De Dietrich Motor

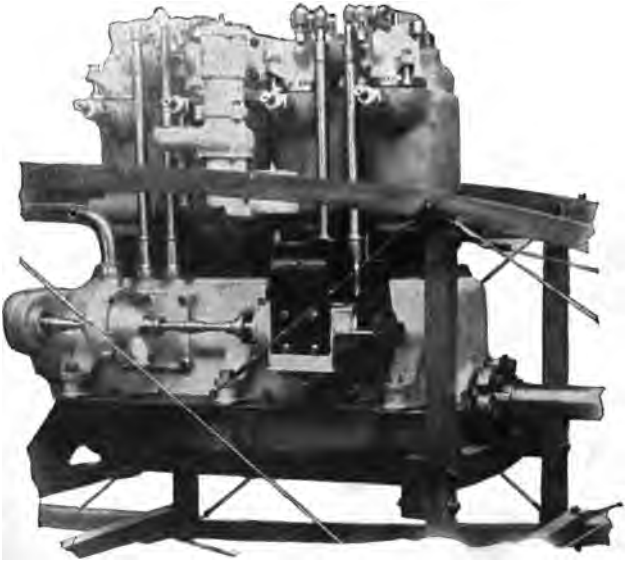

Fig. 25. M. A. B. Aviation Motor

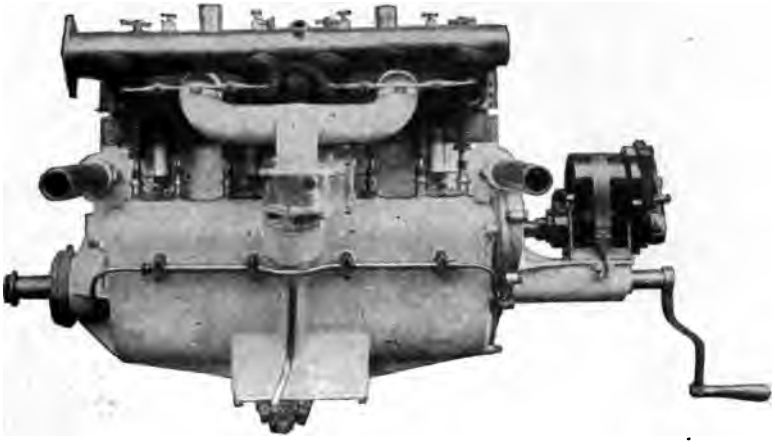

Fig. 26. Aster Aviation Motor

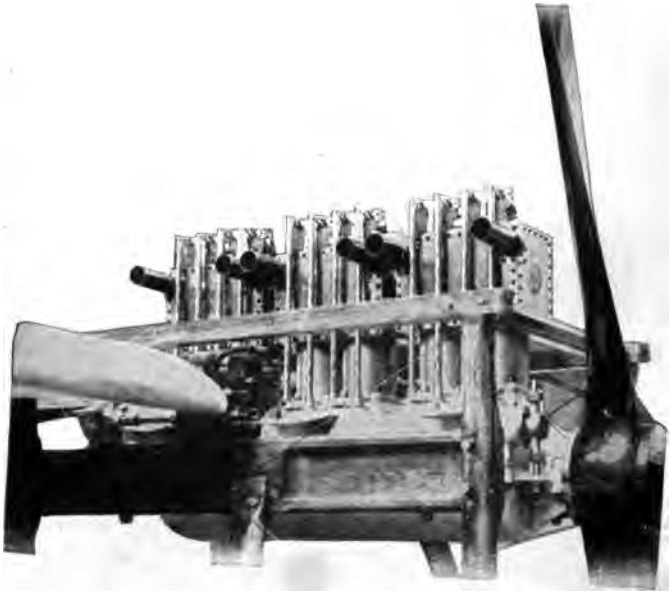

Fig. 27. Buchet Six-Cylinder Mounted on a Bleriot Frame

but it is safe to say that the operation of all these motors would be improved by the use of a flywheel, which would add but very slightly to their total weight.

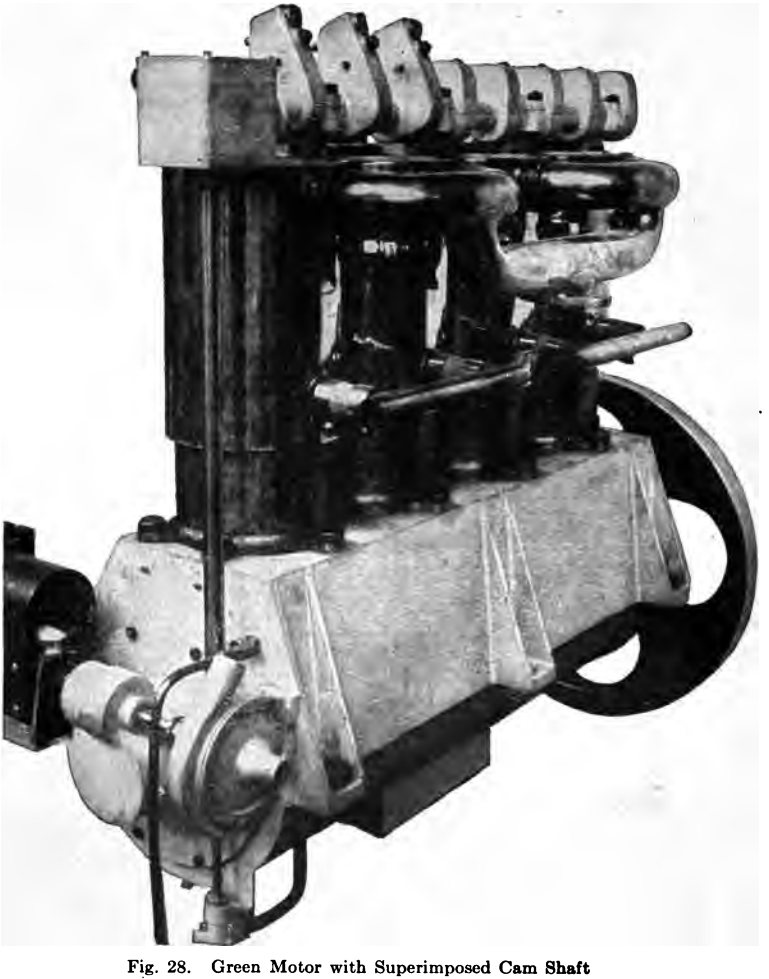

Fig. 28. Green Motor with Superimposed Cam Shaft

An instance of the employment of a superimposed cam shaft is found in the Green, Fig. 28, a motor of English design, while the Gregoire, already referred to, and illustrated by Fig. 29, shows the use of an integral radiator which permits of greatly reducing the weight by cutting down the amount of water required to a fraction

of that ordinarily necessary. This radiator consists of four banks of light copper tubes of small diameter the forward sections of which have two rows of tubes while the after ones have but one row. These tubes terminate in headers at top and bottom on much the same principle as the water-tube boiler, the upper or main headers being of considerably greater diameter than the lower ones. These headers

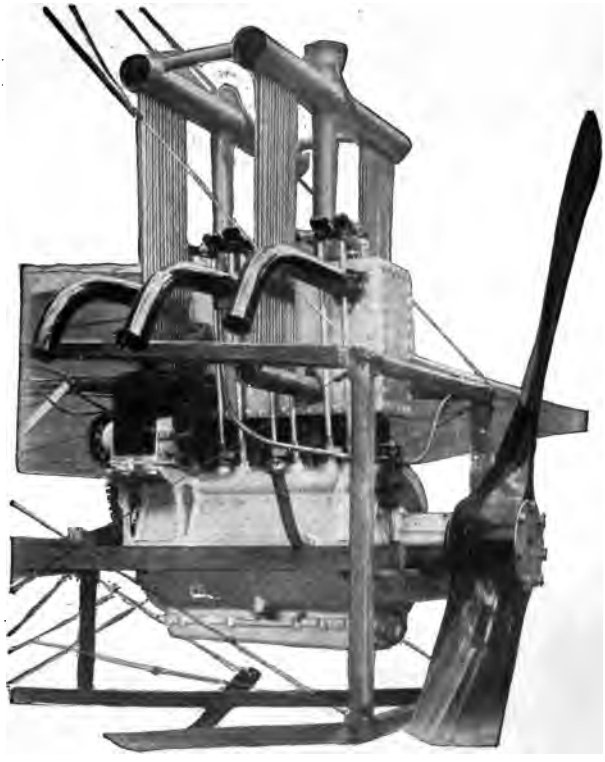

Fig. 29. Gregoire Motor with Directly Attached Radiator

extend entirely across the cylinder heads and outboard for some distance and are connected with the water jackets at the valves, or hottest part. The lower headers are in two parts, directly attached to the lowest part of the jacket at right angles. As the water heats it rises in the large, vertical, uptake tubes, spreads across the upper headers and drops through the banks of small tubes which are cooled by the wind, the circulation being entirely on the thermo-syphon

principle. The four-cylinder motor shown in Fig. 30 is noteworthy chiefly owing to the fact that the very radical departure of

Fig. 30. Four-Cylinder Type with Gear Drive to Propeller Shaft

incorporating a gear drive between the crank shaft and propeller connection as an integral part of the motor has been tried.

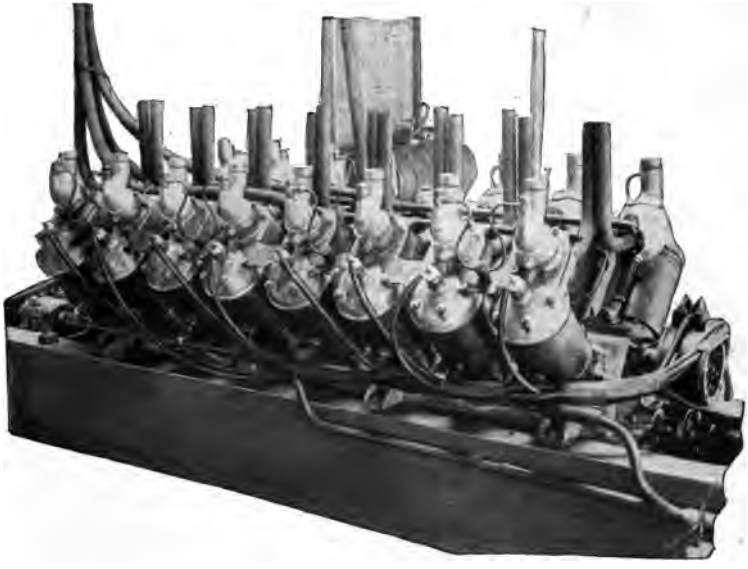

Fig. 31. 100-Horse-Power Sixteen-Cylinder Antoinette Motor

V-Type. *Antoinette.* From the four-cylinder to the eight-cylinder V-type motor is a logical step in the problem of weight saving as this type permits of the use of the same form of crank shaft

of scarcely greater diameter, each opposite pair of cylinders having the big ends of its connecting rods attached to a common crank pin. The Antoinette is the most prominent instance of this, a sixteen-cylinder motor of this class rated at 100 horse-power being shown in Fig. 31. One or two of these have been employed in the Antoinette racing monoplanes, but the eight-cylinder engine shown by Fig. 32, is more commonly employed. This is rated at 55 horse-power and is a later model than the sixteen-cylinder motor shown, having the cylinder heads and valve seats made in one piece from light steel drop forgings, instead of being cast separately as heretofore. The

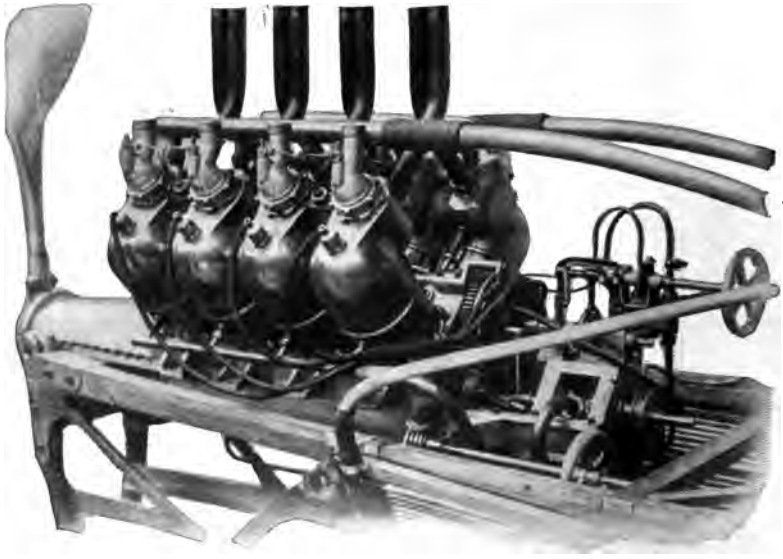

Fig. 32. Eight-Cylinder Antoinette Motor

cylinders are machined inside and outside and the valves are placed one above the other in chambers, the inlet valves being automatic, individual plunger pumps being employed to inject the fuel directly into the valve opening. These pumps are operated by variable throw eccentrics, the travel of which may be adjusted by means of the hand wheel back of the motor which is within reach of the aviator. This controls the amount of power developed by adding or decreasing the amount of gasoline in the mixture, instead of throttling the latter as is ordinarily done. The water jackets are of pure copper and are deposited directly in place on the cylinders by

an electrolytic or plating process. There are thus no joints whatever and the jackets are very light and strong, the method of attaching them to the cylinders being patented.

The water pump is placed at the rear end of the crank shaft in a special casing, a pulley on an extension of the pump shaft carrying a belt which drives a smaller water pump placed at the bottom of the panel of condenser tubes which form part of the triangular forward

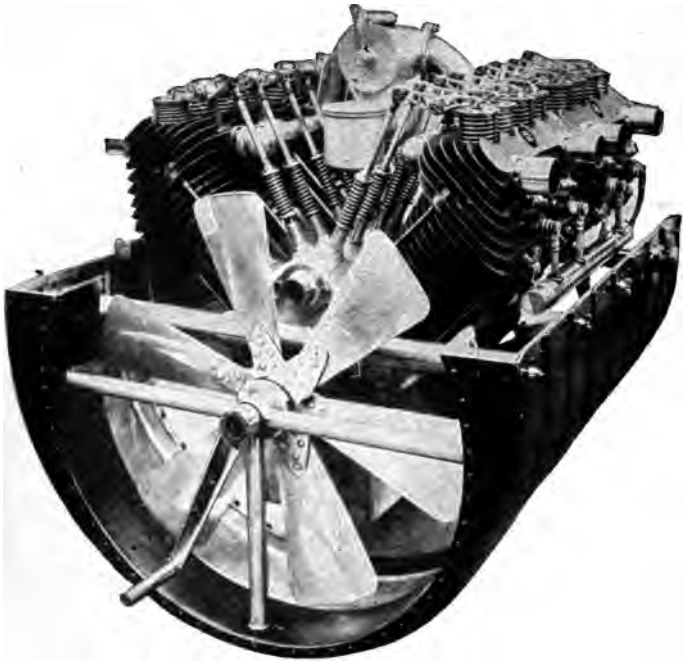

Fig. 33. Fiat Eight-Cylinder Air-Cooled Motor

part of the body of the Antoinette monoplane. These tubes are less than one-half inch in diameter and are extremely light and flexible, their weight forming four-fifths of the complete weight of the condenser, while the headers connecting the tubes constitute the remainder. Horizontally mounted back of the motor is a cylindrical tank employed to separate the steam and water coming from the jackets. At the top of this tank is a pipe leading to the condenser, to carry off the steam collecting in the upper part of the tank. Upon being retransformed into water, it is returned to the tank by the

smaller pump mentioned. This arrangement makes it possible to cool the 55-horse-power motor shown when running constantly under full load, with but three gallons of water. The motor converts one-fourth gallon of water into steam per minute, the con-

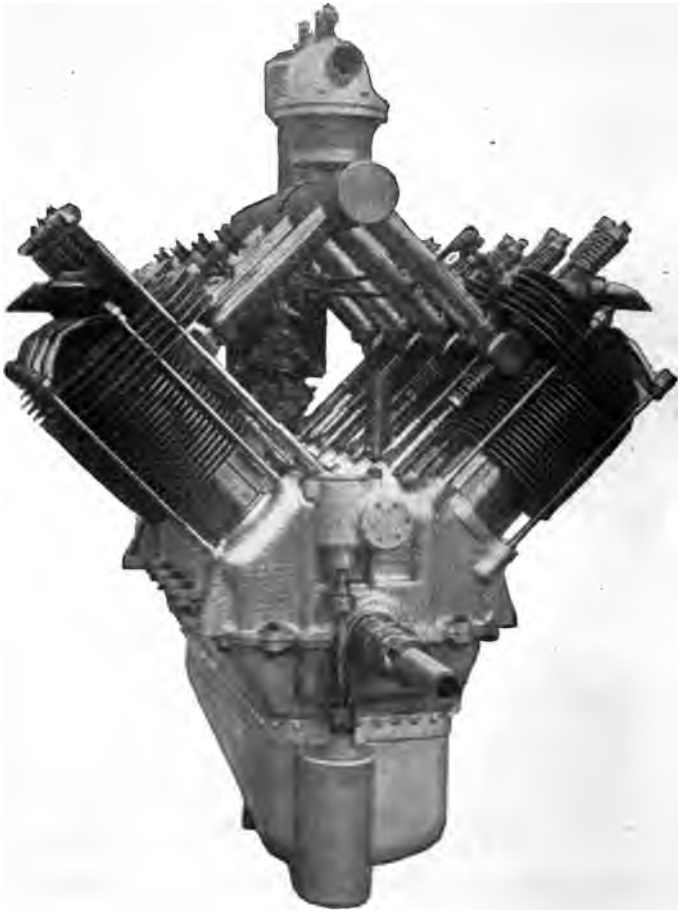

Fig. 34. Renault Air-Cooled Eight-Cylinder Motor. Fan Housing Removed

denser having ample radiating surface to take care of this. As mounted along the body of the monoplane, this condenser does not add perceptibly to the head resistance. Owing to the flexibility of the tubes, it could be mounted on the aeroplane surfaces if desired, though the location already adopted is preferable for many reasons.

Fiat. Fig. 33 shows the Fiat eight-cylinder, V-type, air-cooled motor, in which the valve chambers are placed horizontally despite the 45-degree angle of the cylinders. All the valves are mechanically operated from a single cam shaft through adjustable rods and levers. A separate high-tension magneto is employed for igniting each group of four cylinders, the two magnetos being placed on either side of the crank case at the rear and at an angle of 45

Fig. 35. Renault Air-Cooled Motor with Fan Housing in Place

degrees. They are driven by external timing gears but are protected from below by the sheet aluminum pan shown, the latter forming one-half of the complete housing of the motor, the upper part having been removed to expose its details. A single carbureter placed between the cylinders supplies them all with fuel. The normal r. p. m. rate is very high—1,700 to 2,000 r. p. m., at which the motor develops 35 to 40 horse-power, its maximum being 50 horse-power. The cylinder dimensions are 4.3-inch bore by 4.1-inch stroke.

Renault. Though of smaller dimensions, 3.5-inch bore by 4.7-inch stroke, the Renault air-cooled motor of this type, shown in Fig. 34, is rated at 45 to 55 horse-power with 1,500 to 1,800 r. p. m., the former being its normal speed. In this view it is shown with the air-cooling apparatus removed. All valves are mechanically operated from a single cam shaft, the exhaust being placed directly over the inlet valves, the inlet manifold being so arranged as to obtain the maximum heating effect from the cylinders. An auto-

Fig. 36. Pipe Air-Jacketed V-Type Motor

mobile type, automatic carbureter, entirely of aluminum, vaporizes the fuel, and a high-tension magneto is employed to fire the charge. As will be noted, this carbureter is mounted on the upper side of the center of the inlet manifold. Oil is carried in a large tank beneath the crank case to which it is raised by a pump driven through bevel gearings. The motor is designed so that the propeller of the aeroplane may be mounted either on the crank shaft or on the cam shaft, the turning speed being reduced to one-half that of the normal r. p. m. rate of the motor, in the latter case, or 750 r. p. m. This motor has developed as high as 58 horse-power on a dynamometer test. To

cool it a centrifugal fan of large diameter is mounted in a housing at one end, as shown by Fig. 35. The cold air from the periphery of this fan is led between the cylinders by means of the extended housing shown, finding an outlet at the side between the cooling flanges on the cylinders. Complete with magneto, carbureter, and air-cooling equipment, it weighs 374 pounds, or 6½ pounds per horse-power. It was with one of these motors that Tabuteau won the Michelin prize of $20,000 in 1910 by flying for more than eight hours without a stop, covering close to 400 miles.

Pipe. Another motor of the same type which is air cooled on the same principle as the Renault is the Pipe, of Belgian manufacture, illustrated by Fig. 36. The cylinders are 100 millimeters square, *i. e.*, 3.9 inches bore and stroke. The crank shaft is mounted on three large ball bearings with a ball thrust bearing at one end, the cam shaft also being similarly mounted, with the exception of the provision against thrust. One of the chief features of this motor, apart from the cooling, is the combined inlet and exhaust valve, on the same principle as the Pelterie (French) and the Franklin (American) motors. It consists of a sliding sleeve, bell mouthed at its lower end to form the exhaust valve, and the seat for the inlet valve as well. This is illustrated in section by Fig. 37. The inlet valve G is concentric with the sleeve S, its stem R passing through the hollow stem of S, and it seats upon it at H. The seat for S in the cylinder head is at J. The two valves thus formed are provided with suitable retaining springs and are operated by the levers OO' and PP'. P is forked to surround R and bear upon the cap V surmounting S. S forms a piston and is provided with two piston rings just below the inlet ports DD, to prevent the exhaust gases from leaking into the inlet pipe when being expelled through the

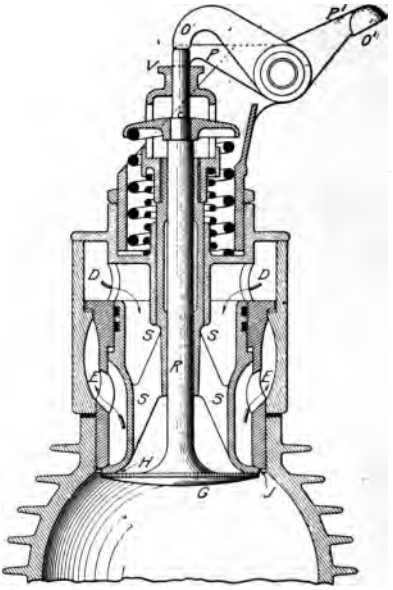

Fig. 37. Combined Inlet and Exhaust Valve of Pipe Motor

exhaust ports *EE*. When *G* is opened by the rocker arm *O*, gas is drawn from the carbureter through *DD* and down through the hollow sleeve *S*. At the end of the working stroke, the sleeve *S* is moved downward from its seat at *J* by the forked rocker arm *P*, the exhaust gases then being expelled through the ports *EE*. The passage of the cool gases through the center of *S* prevents both the inlet and exhaust valves from warping due to the heat and is thus of great advantage on an air-cooled motor. Two blowers of special form, one at each end of the crank shaft, force a large volume of air through the aluminum jackets and over the cooling flanges of the cyl-

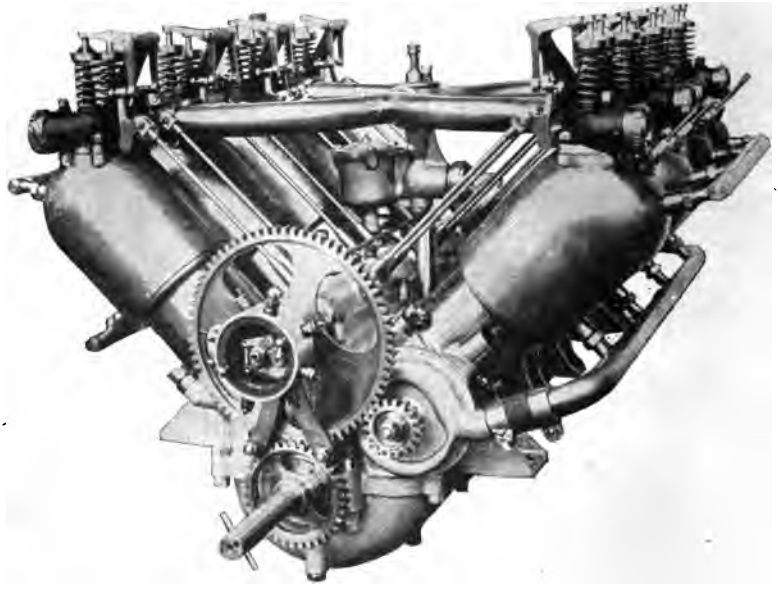

Fig. 38. Bruhot Eight-Cylinder Water-Cooled Motor

inders similar to the American Frayer-Miller engine. The Pipe motor complete weighs 288.8 pounds, or about $5\frac{3}{4}$ pounds per horse-power.

Water-Cooled Types. Examples of water-cooled, eight-cylinder, V-type motors are illustrated in the Bruhot (French), Fig. 38, and the Wolseley (English), Fig. 39, two of the latter of 200 horse-power each being used on the ill-fated British airship Mayfly.

Fan and Star Types. *Anzani.* It will be noted that few, if any, of the four-cylinder or eight-cylinder motors just described, whether air- or water-cooled, weigh less than 5 pounds per horse-

power, while most of them exceed this. To considerably reduce this figure, the fan or star arrangement of the cylinders has been resorted to. In its simplest form this is shown by the Anzani two-cylinder,

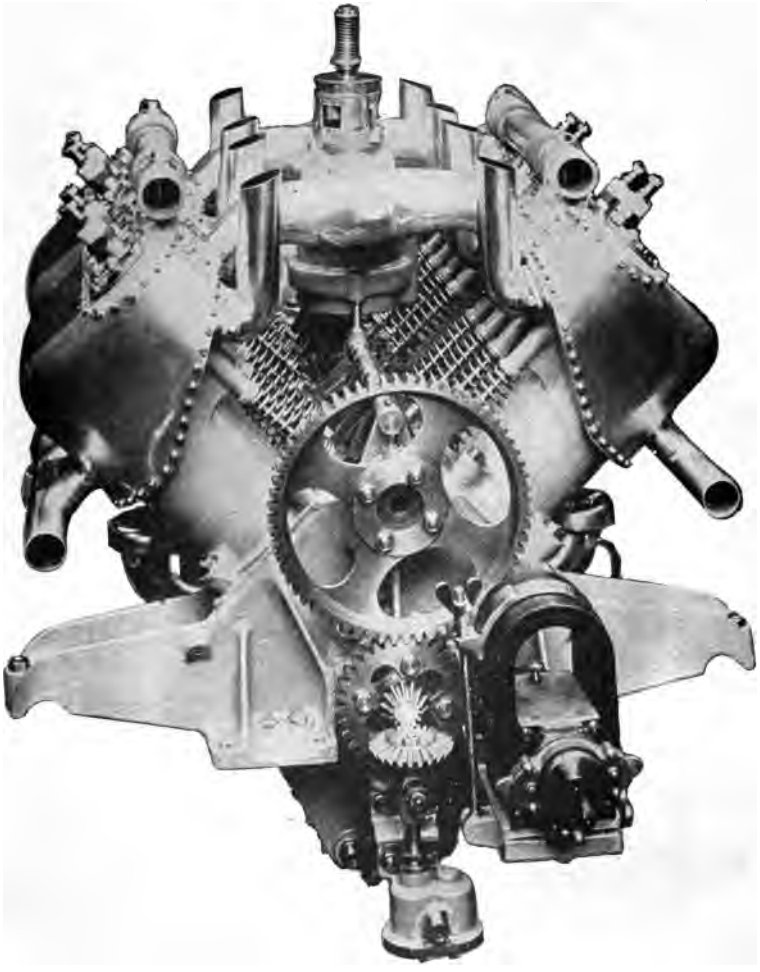

Fig. 39. Wolseley Eight-Cylinder Water-Cooled Aviation Motor

air-cooled motor, Fig. 40. In reality, this is nothing more or less than a section of the usual eight-cylinder V-type. Cooling is by means of sheet-metal, perforated flanges pressed on the cylinders.

M. A. B. A closer approach to the fan formation is seen in the

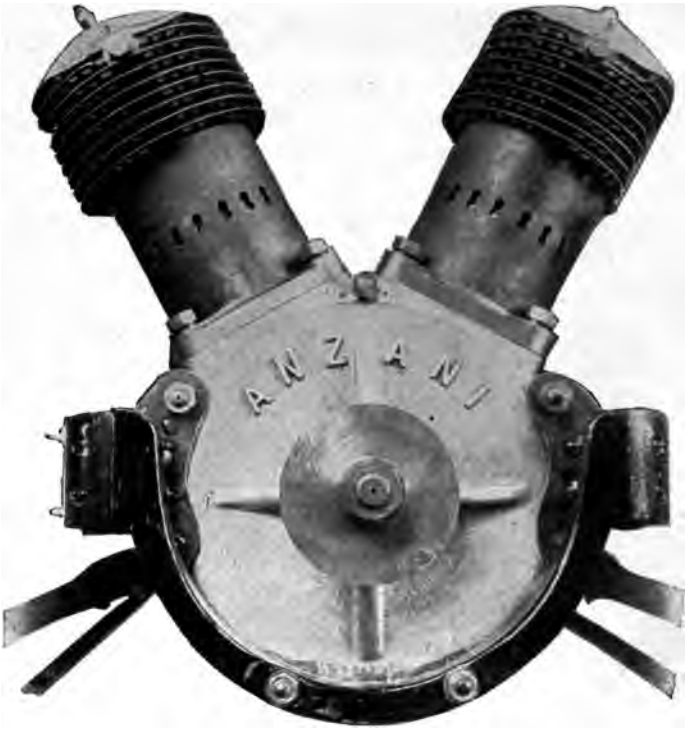

Fig. 40. Anzani Two-Cylinder V-Type Motor

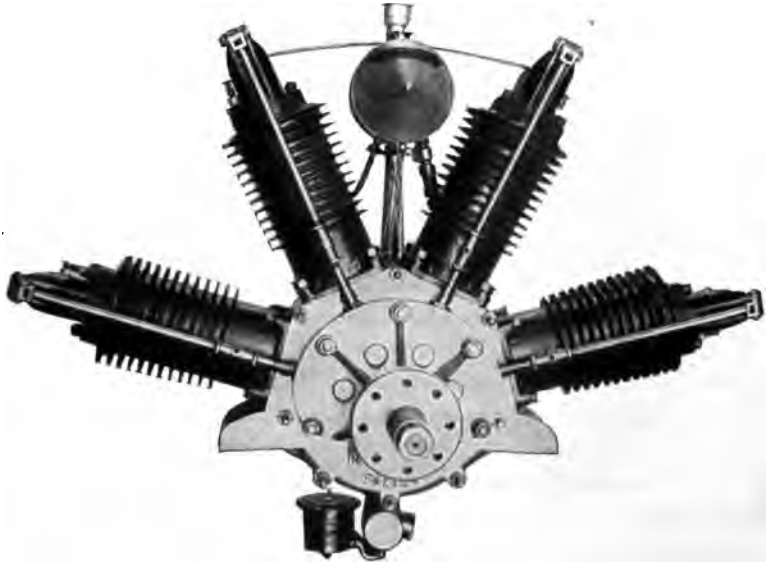

Fig. 41. M. A. B. (Italian) Four-Cylinder Motor

M. A. B. (Italian) four-cylinder motor, Fig. 41. In this case, as in those following, the flanges are cast integral with the cylinders.

Farcot. A further extension of the same principle is shown in the Farcot (French), Fig. 42, this having six air-cooled cylinders. The same makers also manufacture a motor in which the cylinders are mounted radially around a circular crank case, the latter with its cylinders lying horizontally, the crank shaft running vertically. On its upper end it carries a seven-bladed horizontal fan to cool them.

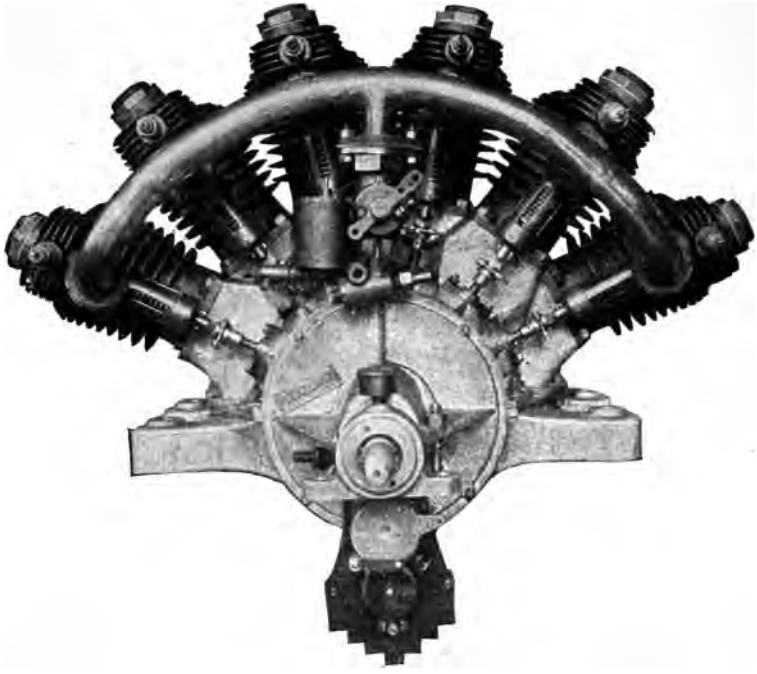

Fig. 42. Farcot Fan Type Air-Cooled Motor

This arrangement of cylinders grouped symmetrically around a central crank case is not new, Forest having employed it in 1888, and Manley in 1900 for aeronautic motors, the former building a 50-horse-power, eight-cylinder motor of this type with the then light weight of 11 pounds to the horse-power. Manley produced a 52-horse-power, five-cylinder motor with a weight of but 2.4 pounds per horse-power, or 125 pounds total weight. It developed full power for ten hours under constant load and was subsequently

employed by Professor Langley in his full-sized aerodrome. The number of cylinders and their arrangement in a motor of this type have much to do with the balance, regularity of cycle, lack of vibration, and smoothness of running. A four-cylinder motor of this type is nearly in perfect balance so far as centrifugal force is concerned, a suitable counterweight making up for any deficiency. With two sets of four cylinders working on two cranks at 180 degrees, the balance is better still—the more so the nearer together the planes

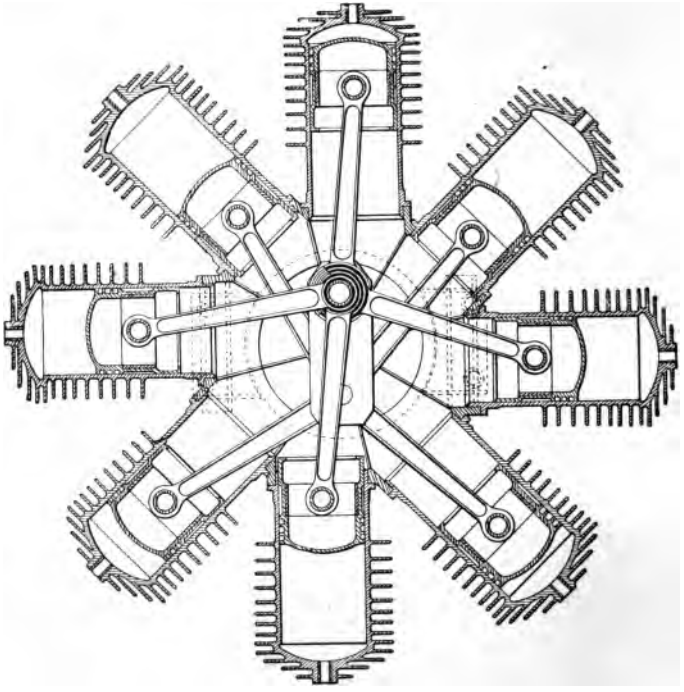

Fig. 43. Cross-Section of Farcot 50-Horse-Power Air-Cooled Motor

of the two sets of cylinders. The relative positions of the pistons, connecting rods, and cranks in an eight-cylinder Farcot motor of this type is shown in section, Fig. 43.

Each group of four cylinders is necessarily in a different plane to permit of attaching the different connecting rods to the two cranks, but by offsetting the rods, the distance between the planes of the two groups has been reduced to one inch. The cranks are at

180 degrees and alternate cylinders are in different planes. As the crank shaft is vertical, a horizontal shaft driven through bevel gears

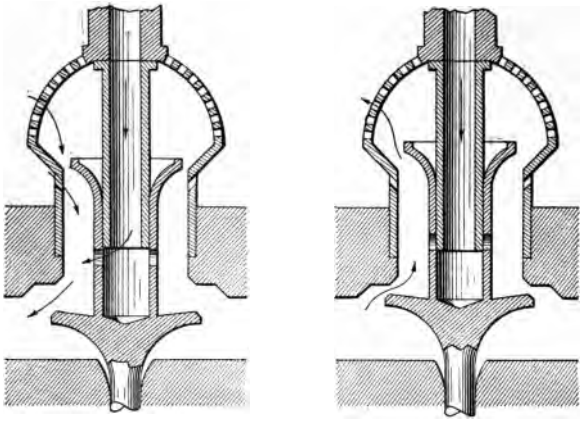

Fig. 44. Farcot Combined Valves, Inlet and Exhaust Positions

at a lower speed is provided for attaching the propeller. A combined exhaust and inlet valve similar to that of the Pipe is employed,

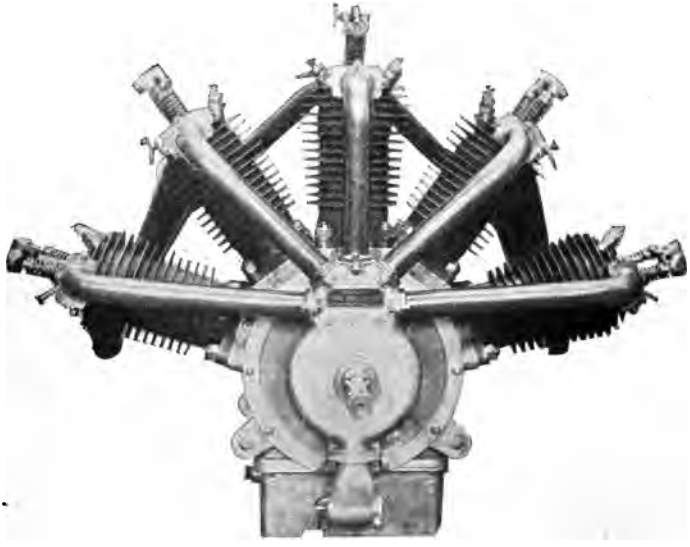

Fig. 45. R. E. P. (Pelterie) Five-Cylinder Motor

Fig. 44. Lubrication is by means of a gear pump forcing oil through the hollow crank shaft and the perforations in the latter leading up

through the connecting rods. Two small, high-tension magnetos, one set a quarter turn behind the other, provide ignition. The Farcot eight-cylinder, horizontal, circular motor is made in three sizes, 30, 50, and 100 horse-power, the weight being but 2.2 pounds per horse-

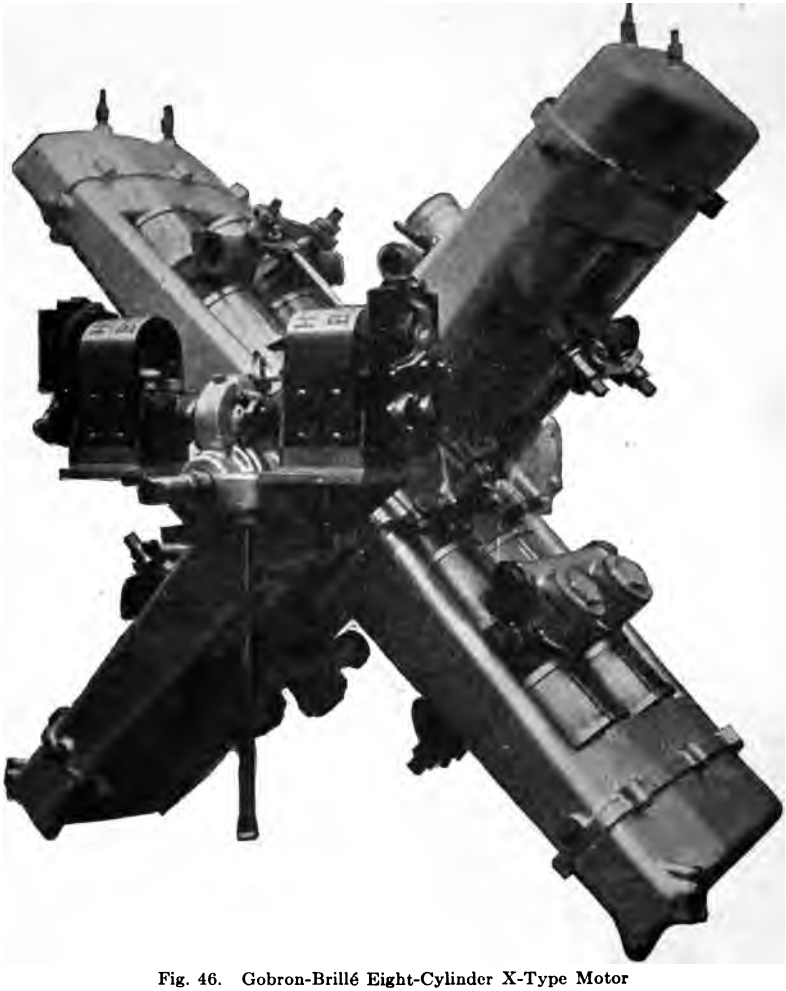

Fig. 46. Gobron-Brillé Eight-Cylinder X-Type Motor

power. Both magnetos weigh only 15 pounds, whereas the ordinary high-tension magneto alone weighs 25 to 30 pounds. It is claimed that the 50-horse-power Farcot motor may be made to develop as high as 70 horse-power for a short period.

Clement. The new Clement aeronautic motor resembles the Farcot in general arrangement, but differs considerably in detail. It has seven water-cooled cylinders, all in the same plane, the connecting rods of which are attached to a single crank. A double counterweight, acting as a flywheel, gives almost perfect balance. The normal r. p. m. rate of the motor is 1,200, but the propeller is driven at 800 r. p. m. by means of a second horizontal shaft operated through bevel gearing, as in the Farcot. The cylinders are of specially heat-treated steel, while the heads are cast steel, screw threaded

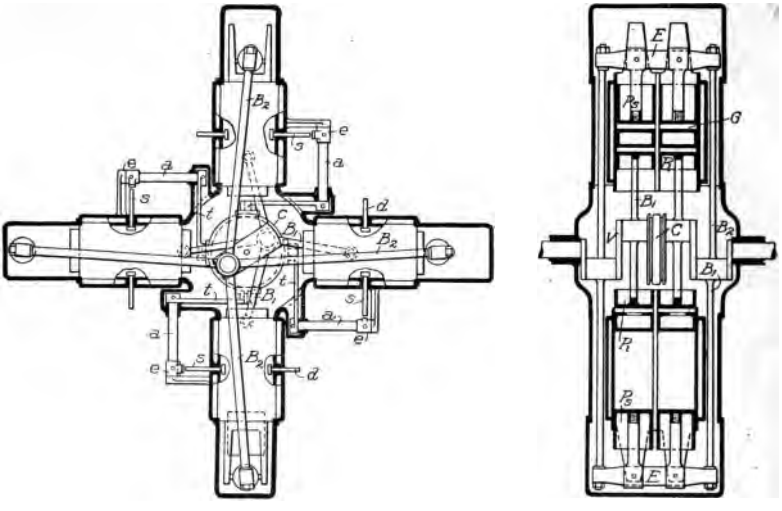

Fig. 47. Side and Edge-On Sections of Gobron-Brillé Motor

and turned onto the cylinders, after which they are solidly welded in place, thus eliminating many small fastenings. The valves are in the heads and are held on their seats by small flat springs, the rocker arms having the usual helical springs. The pistons are of pressed steel, with convex heads, giving a combustion chamber whose general shape is ellipsoidal. The valves are operated by a single cam revolving in the same direction as the crank shaft and at but one-eighth its speed through gearing. There are four high points and four depressions in this large cam, corresponding, respectively, to the opening of the exhaust and inlet valves, the slow speed putting very little wear on the valve-operating mechanism, while the occurrence of the impulses regularly, two-sevenths of a revolution

apart, gives very smooth running. There are three principal connecting rods, to which the other four are attached. These three principal rods are carried upon two sets of balls, one upon the inner two rings and the third on the intermediate pair. The crank pin is removable to permit of slipping into place the sleeve to which the connecting rods are attached. This sleeve carries the two counterweights. The high-tension magneto for ignition is driven directly from the crank shaft while a separate distributor runs at half its speed. The carbureter is located beside the crank case and connects by a short pipe to a common chamber in which all the inlet pipes terminate.

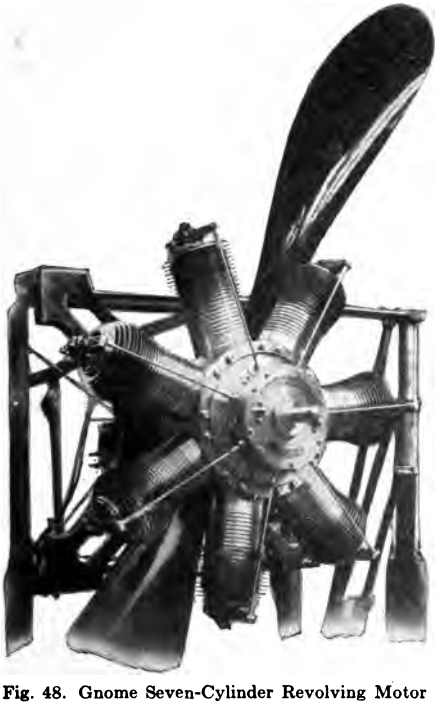

Fig. 48. Gnome Seven-Cylinder Revolving Motor

The water-circulating pump is placed about the crank shaft and forces the water directly to the bottom of the copper water jackets, which are soldered and clamped in place. The radiator of 32¼ square feet of radiating surface weighs but 26½ pounds with its tank of water. The cylinder bore is 4.3 and the stroke 4.5 inches, the motor developing 50 horse-power at 1,200 r. p. m. The diameter of the motor overall is 3 feet and its total weight in working order is only 154.3 pounds, or 3.8 pounds per horse-power. In general design and arrangement it resembles the Manley motor of 1900 built for Langley's aeroplane. The first of these Clement motors is mounted on the Clement monoplane.

Pelterie. The Pelterie (R. E. P.) is a representative fan type which attracted considerable attention by reason of its ingenious design when first placed on the market. It is built in five-, seven-,

and ten-cylinder models, one of the first being shown by Fig. 45. They are of 25, 35, and 50 horse-power, respectively, the 25-horse-power model being the one illustrated. The cylinders are of the same size in all and are very small, 2.8-inch bore by 3.7-inch stroke.

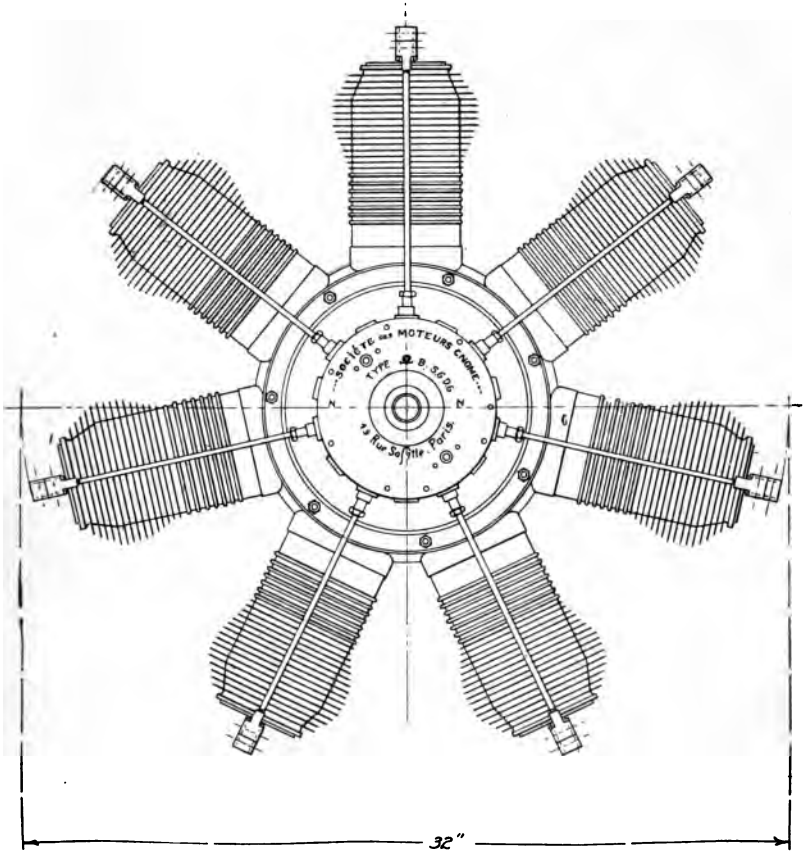

Fig. 49. Detailed Side View of Seven-Cylinder Gnome Motor

In the five-cylinder type, all the cylinders are in the same plane, while in the seven-cylinder, they are staggered, all the connecting rods being attached to a common crank pin by offsetting. The ten-cylinder motor is really two fives placed side by side and very close together. Combined inlet and exhaust valves of the form already described are employed. Two carbureters are employed on the ten-cylinder motor, with a double magneto.

Gobron-Brillé X-Form. One of the most radical departures from current practice is found in the Gobron-Brillé, Fig. 46, which has eight cylinders arranged in **X**-form, each cylinder having two pistons. The explosion takes place between the pistons which are thus driven apart, the connecting rods of the inner pistons being

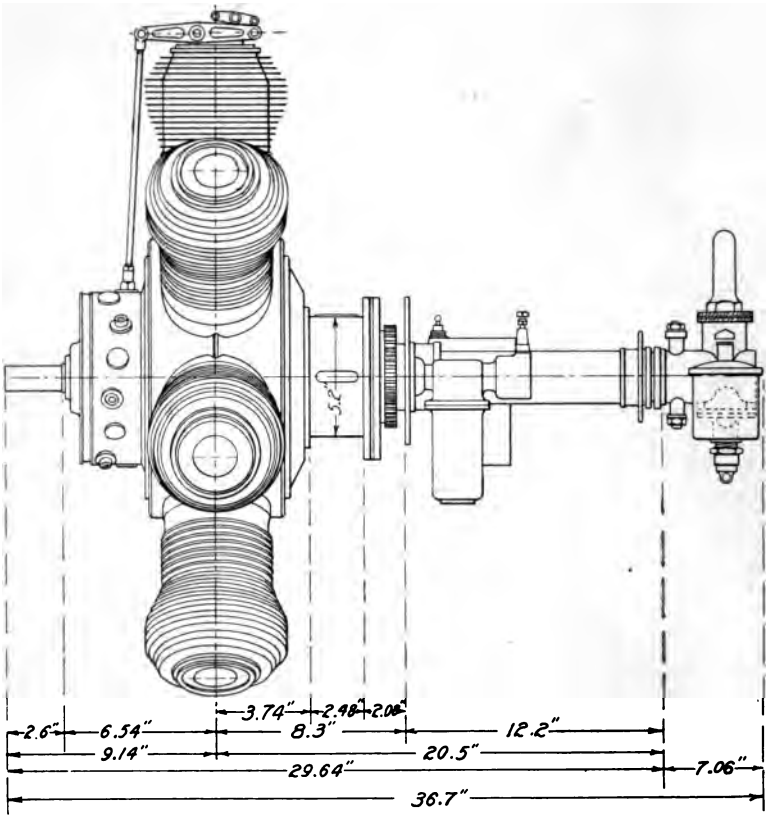

Fig. 50. End View of Seven-Cylinder Gnome Motor, Giving Dimensions

attached directly to the two-throw crank shaft in the usual manner, while the upper pistons transmit their power to the same cranks through long connecting rods passing outside of the lower pistons, but encased in a housing, so that the exhaust-valve-operating mechanism is the only moving part in view. The action of this is illustrated by Fig. 47. Above the exhaust valves of each group is placed a

double rocker arm, which, at each turn of the shaft, opens one or the other of the two valves. To obtain the movement, each of the rocker arms *e* is fastened to a shaft *a* which is given a reciprocating movement by the lever *t*, attached to its other end. On the end of *t* is a shoe or follower, running in one or the other of the two grooves

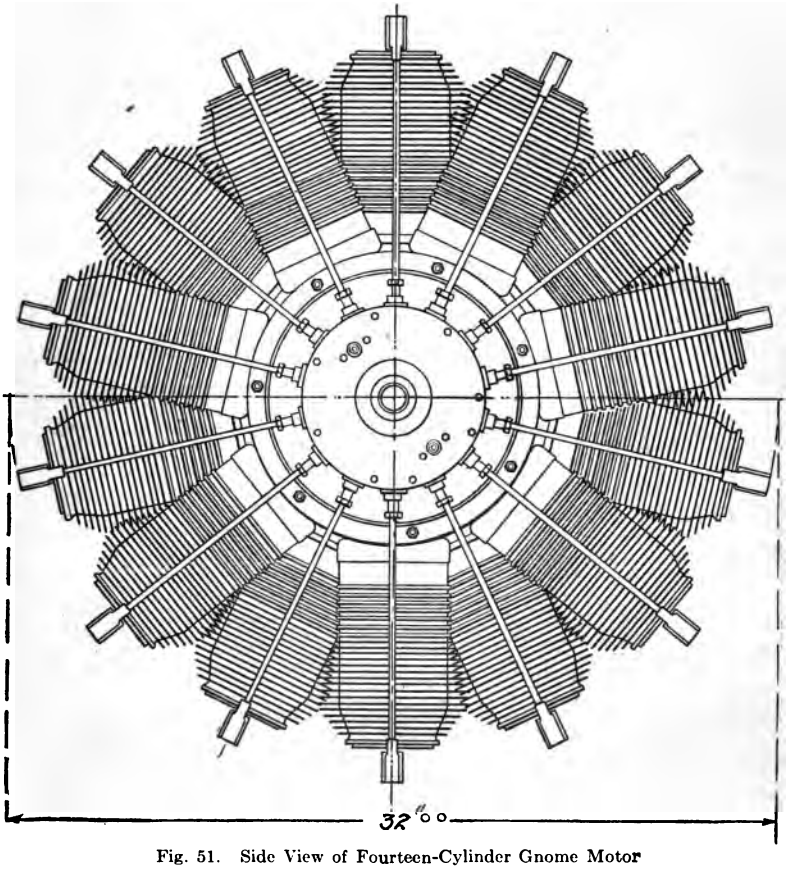

Fig. 51. Side View of Fourteen-Cylinder Gnome Motor

in the double cam *c*, keyed in the crank shaft. The two grooves cross at a certain point, thus switching the shoe from one to the other alternately. The inlet valves are all automatic, and are fed from a single carbureter, the inlet piping being so arranged that the course taken by the gas from the carbureter to every one of the cylinders is the same. Ignition is provided by two magnetos driv-

ing through worm gearing and a shaft at right angles to the crank shaft, the magnetos revolving in opposite directions. A gear pump forces oil to all moving parts inside the crank case, while a centrifugal pump circulates the water, of which but four gallons are necessary. It generates 75 horse-power on a total weight of 330 pounds, or 1 horse-power for every 4.4 pounds, making it one of the lightest

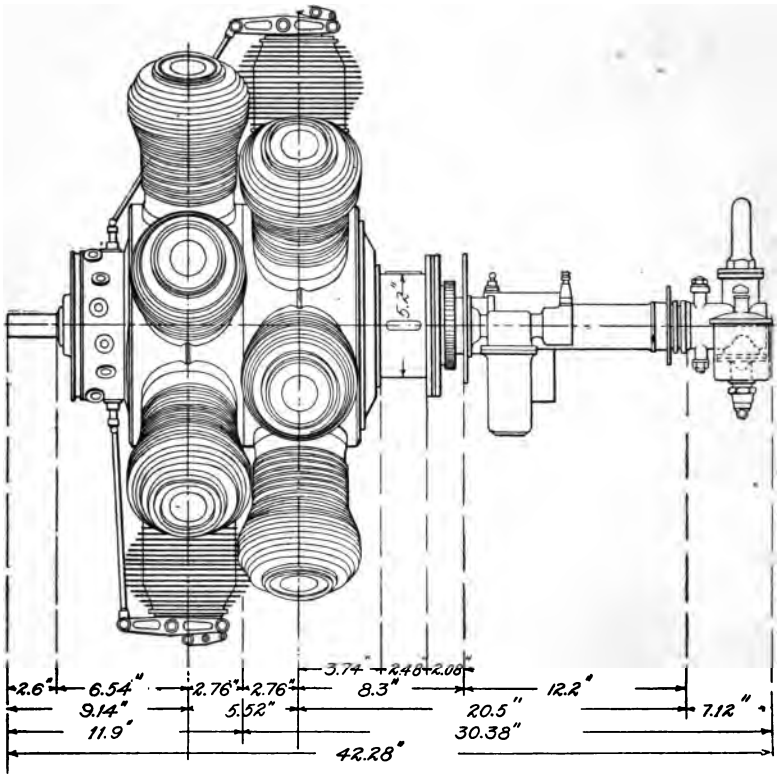

Fig. 52. End View of Fourteen-Cylinder Gnome Motor, Giving Dimensions

water-cooled motors. Automobiles of the same make have been equipped with motors operating on this principle, for several years.

Gnome Revolving-Cylinder Type. While the revolving-cylinder motor has been known for a number of years—the Adams-Farwell (American) being one of the first successful motors of this type did not come into great prominence until 1910, and this mainly through the performance of the Gnome motor on the numerous

French machines competing at the International Meet (October, 1910). The Gnome motor is built in 50- and 100-horse-power models, the former of seven, shown in Figs. 48, 49, and 50, and the latter of fourteen cylinders—really two seven-cylinder motors, Figs. 51 and 52. The weight of the 100-horse-power model complete is 220 pounds, or 2.2 pounds per horse-power, which appears to be the minimum reached in a practical unit. The material and machine work throughout are of the very finest, the motor revolving in practically perfect balance. It is estimated, however, that the seven-cylinder motor expends at least 7 horse-power in overcoming the resistance of the air due to its revolution, the cylinders having air-cooling flanges which taper broadly near the heads, thus presenting considerable surface. The cylinders are mounted symmetrically about a drum-shaped crank case, as in the Clement, and have large exhaust valves placed in the heads and operated by rocker arms. The inlet valves are placed in the heads of the pistons and are automatic so that centrifugal force is taken advantage of to draw in the fuel as well as to expel the burnt gases through the exhaust valves. Both valves are counter-weighted to neutralize this force. The bore is about 4.4 inches and the stroke 4.8 inches, all seven connecting rods being attached to a common crank pin, or to a two-throw crank pin in the fourteen-cylinder type, *i. e.*, one rod acts on the pin and the others are articulated to it. Fuel is admitted to the crank case through the hollow crank shaft to one end of which the carbureter is directly attached, while lubricating oil is injected in the same manner by means of a two-cylinder reciprocating pump, with two distributors.

An improved model of the seven-cylinder Gnome was brought out during 1911. This is rated at 70 horse-power and the first of this type completed was brought to the United States by Earle Ovington on his new Bleriot monoplane with the "inverse curve" form of tail. It requires a skilled mechanic, thoroughly familiar with the Gnome construction, to dismount the 50-horse-power model, but in the new 70-horse-power model it is only necessary to remove a few nuts to take off the front half of the crank case, leaving the cylinders readily detachable, while the method of clamping them has also been made much more secure. The receptacles into which the spark plugs are screwed are internally threaded steel tubes

welded into the side of the cylinder by a secret process, while the automatic inlet valves, balanced by counterweights to offset the action of centrifugal force, are made so that they can be withdrawn through the cylinder heads, making it unnecessary to take down the engine for this purpose. It was with one of the new 70-horse-power Gnome motors that Weyman won the 1911 Gordon-Bennett in a Nieuport monoplane.

As the motor revolves at 1,300 r. p. m. normally, the centrifugal force is terrific and the oil is practically pumped right through the motor—or, in other words, pumped in and thrown out. Castor oil is employed for the purpose and the consumption is very great—at least half a gallon of lubricant being necessary for every gallon of gasoline used. The consumption of fuel is also very high—300 grammes per horse-power hour—about 10.6 ounces of gasoline, or about 44.1 pounds per hour for the 50-horse-power motor and close to 90 pounds per hour for the 100-horse-power motor, which, with lubricant, would make 100 pounds of gasoline and oil to run the larger motor one hour. This extravagant consumption of fuel and oil, particularly such high-priced lubricant as castor oil, is the chief drawback of the revolving-cylinder motor, and the latter will undoubtedly have to be improved in this respect if it is to maintain its lead.

More than 500 Gnome revolving motors have been built and it has to its credit almost every world's record for 1910 except that of altitude (Wright), and including such events as the Gordon-Bennett Cup, London to Manchester, Paris-London, Crossing the Alps, Statue of Liberty, *Circuit de L'Est*, and other important speed, as well as altitude, and endurance flights, more than $500,000 in prize money having been won during 1910 alone in machines equipped with Gnome motors.

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